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Camacho

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[54] **LONG ARC COLUMN FORMING PLASMA GENERATOR**

[75] Inventor: **Salvador L. Camacho,** Raleigh, N.C.

[73] Assignee: **Technology Application Services Corporation,** Raleigh, N.C.

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[52] **U.S. Cl.** ..... **219/121 P,** 219/75, 313/231

[51] **Int. Cl.** **B23k 9/00**

[58] **Field of Search** ..... 219/121 P, 74, 75; 313/231, 111; 13/9, 31

[56] **References Cited**

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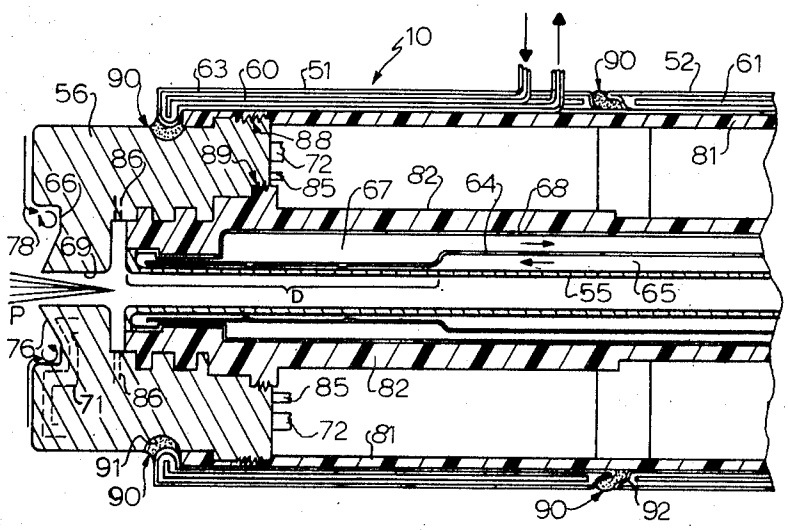
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Primary Examiner—J. V. Truhe
Assistant Examiner—G. R. Peterson

[57] **ABSTRACT**

In an improved long arc column forming plasma generator an aerodynamic nozzle face configuration and a novel two part insulated housing cooperate to substantially reduce so-called "double arcing" of the plasma column and damage to the plasma generator caused therefrom.

7 Claims, 6 Drawing Figures



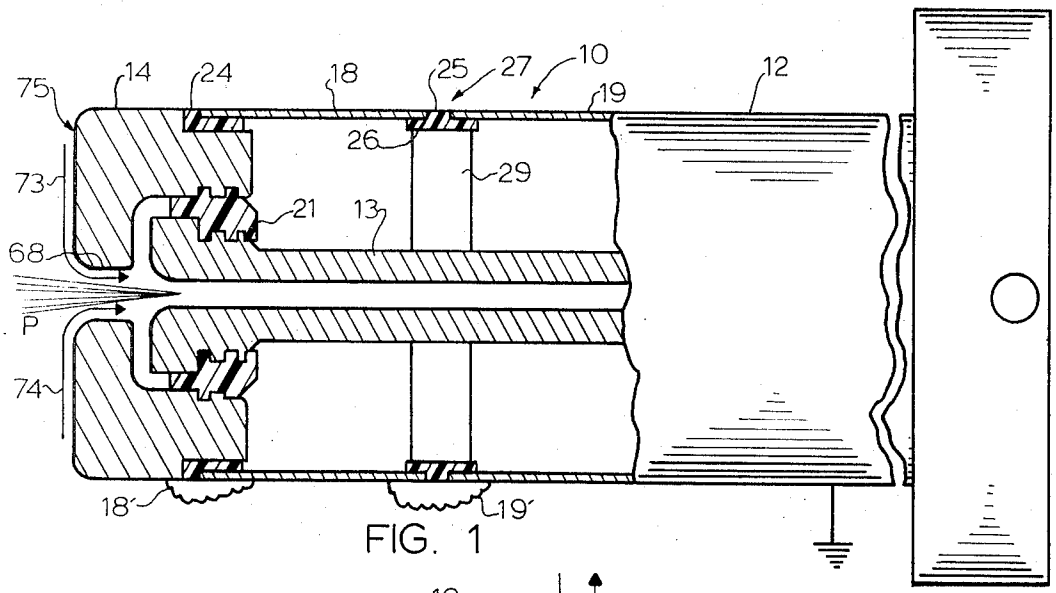


FIG. 1

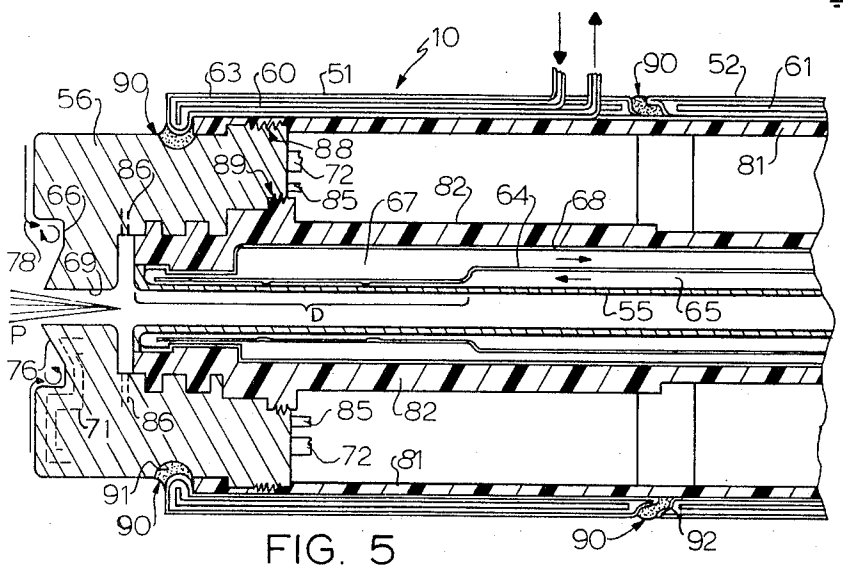


FIG. 5

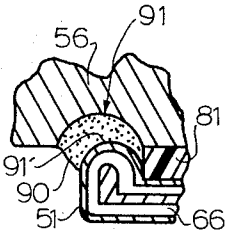


FIG. 6

PRIOR ART

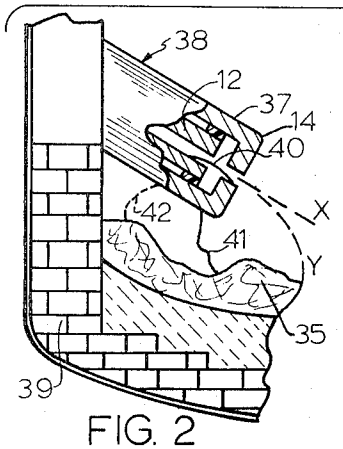


FIG. 2

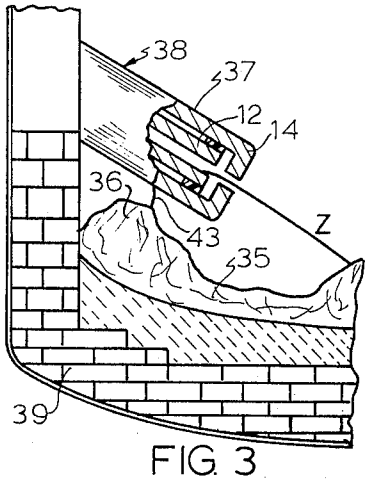


FIG. 3

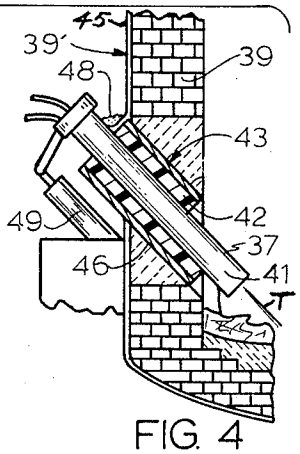


FIG. 4

LONG ARC COLUMN FORMING PLASMA GENERATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to plasma arc devices and methods and particularly to those devices and methods adapted for double arc abatement.

2. Description of the Prior Art

Methods and apparatus for generating a long (i.e., 12–40 inches) plasma arc column have been known. In what is perhaps the closest known prior art there is disclosed in U.S. Pat. No. 3,673,375 a long arc column forming plasma generator. In this patent recognition is given to the importance of the relation between nozzle internal diameter, nozzle length, and vortex chamber width in obtaining a long directionally stable plasma arc column greater that 12 inches, while minimizing internal electrode deterioration. While this disclosure constitutes a significant advance in the art a need for further improvement has been revealed.

Such long arc column forming plasma generators as described in the above cited reference and elsewhere in the prior art, have characteristically included a cylindrical internal electrode forming a gas vortex chamber within itself, a gas directing nozzle located forwardly of and insulated from the cylindrical electrode, and a cylindrical outer housing secured to the nozzle and enclosing the electrode. That portion of the cylindrical outer housing residing in proximity to the nozzle has in the past been electrically connected to the nozzle and susceptible to damage from so-called "double arcing" of the plasma column.

"Double arcing" occurs in one case when one arc is formed inside the generator between the internal electrode and the nozzle, and another arc is formed outside the generator between the nozzle and a workpiece also in the electrical circuit. In another case, double arcing may occur, for example, during scrap steel melting when a transferred plasma arc is formed between the internal electrode and a metal scrap and another return arc is formed between another portion of the scrap and the generator housing. In either case, substantial damage to the nozzle, housing or both nearly always results. Although methods and apparatus for abating double arcing have been attempted in the past, none have proven commerically successful.

Furthermore, a long arc column forming plasma generator of the class described has heretofore often been mounted in a furnace or the like by means of an insulated collar to prevent grounding of the generator housing against the furnace mountings. Such grounding shorts the electrical circuit preventing operation in most installations and at the same time poses a severe shock hazard to personnel in the area of the mounting apparatus. U.S. Pat. No. 3,689,732 is broadly related to this invention in its teaching of a sleeve formed from an electrical insulator which is adapted for use on a hand held electric arc device. Such a sleeve, however, would be wholly unsuited to the needs of the present invention with respect to double arc abatement, due to its inability to withstand the extremely high temperatures of a plasma arc column without rapidly deteriorating. It would, therefore, serve no practical purpose for double arc abatement on such a plasma generator.

Based on the above, there is a need for an improved long arc column forming plasma generator which is no longer susceptible to damage from double arcing, which is capable of being grounded directly to a mounting device thereby eliminating the need for an insulated mounting collar of lining, and which at the same time is able to effectively circumvent the possiblity of severe electrical shock to personnel in the area of a generator mounting device.

SUMMARY OF THE INVENTION

The method and apparatus of the present invention are directed to an improved long arc column forming plasma generator based on the long arc column forming plasma generator taught in the above cited U.S. Pat. No. 3,673,375. An improved long arc column forming plasma generator according to the invention is primarily directed at the abatement of double arcing of the plasma column and comprises a two part cylindrical insulated and water cooled housing and an improved nozzle face configuration. One member of the two part housing is adapted to overlay the rearward or mounting end of the generator, while a second housing member is adapted to overlay the forward or nozzle end of the generator. Once installed, the respective housing members are adapted to be electrically insulated from each other as well as from the generator nozzle and internal generator parts. The result is that the plasma column is in no way attracted to the housing member overlaying the nozzle because of its isolation from the electrical circuit. Double arcing to the housing is thus effectively prevented. Moreover, in order for the arc column to double arc to the rear housing member or that housing in closest proximity to the mounting end of the generator, it must traverse the forward housing member by forming two external arcs simultaneously. The likelihood of this occurrence is very small. In addition, water cooling of the housing members further limits the possibility of a double arcing situation since an arc column will be attracted to hotter rather than cooler surfaces as is well-known. Finally, this invention contemplates the use of an aerodynamic nozzle face configuration which is adapted to cause a non-laminar flow of air across the nozzle face during operation of the arc column. The result is a greatly stabilized arc column and substantial reduction in double arcing and resulting damage to the nozzle.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial cross sectional view of a long arc column forming plasma generator based on those of the prior art, which has been modified in accordance with the invention.

FIGS. **2** and **3** show cases of the prior art in which destructive "double arcing" has been known to occur.

FIG. **4** shows a prior art plasma generator in a typical insulated mounting in which the accumulation of "kish" has caused short circuiting across a prior art insulated mounting collar resulting in damage to the insulator as well as the generator.

FIG. **5** is a detailed broken view of a plasma generator of the preferred embodiment.

FIG. **6** is a somewhat enlarged cross sectional view showing an insulated joint employing Fibrefrax insulation according to the preferred embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, an improved long arc column forming plasma generator constructed according to one embodiment of the present invention is generally designated 10. Such improved plasma generator is herein shown in simplified form to eliminate unnecessary and well-known internal construction details. The particular embodiment shown in FIG. 1 represents a plasma generator of the prior art which has been adapted to receive a two-part cylindrical housing 12 according to this invention. Generally, such a plasma generator of the prior art has included a cylindrical internal electrode 13 and a gas directing nozzle 14 forwardly spaced and insulated from said electrode 13. Other conventional parts are included such as gas, water and electrical supplies. Known long arc column forming plasma generators of the prior art have also included a one-piece cylindrical housing (not shown) secured to the nozzle 14. Reference is made by way of example to previously cited U.S. Pat. No. 3,673,375 issued to the same inventor, and specifically to FIG. 1 of that patent which shows the described unitary housing. Such prior art housings have been in physical as well as electrical attachment with the nozzle and as previously mentioned any current above ground which the nozzle received by way of a "double arcing" condition, later described in detail, was also passed through the entire housing. Referring still to FIG. 1 this invention provides a housing comprised of at least two separated and insulated members 18, 19 instead of the prior art unitary housing in order to prevent such "double arc" induced current from being connected with such housing. A first cylindrical housing member 18 is adapted to be secured via an appropriate electrical insulator 24, to said nozzle 14. Securement is made by appropriate threaded or forced fit connection such that insulator 24 is effectively sandwiched between housing member 18 and nozzle 14. A second cylindrical housing member 19 is adapted to be located rearwardly of and slightly spaced from said first housing member 18. Additional electrical insulating material is adapted to line the space 26 formed at the joint 27 between housing members 18 and 19. Housing members 18 and 19 are preferably formed from stainless steel. Insulators 24 and 25 are preferably formed from "Synthane" insulating material and may assist in supporting housing members 18 and 19 in addition to providing electrical insulation therebetween. Additional internal support of insulator 25 and housing members 18 and 19 may be provided by radial support members 29. Finally, insulated separation of housing members 18 and 19 from each other and from nozzle 14 enable the rearward housing member 19 to be grounded directly to furnace mountings or the like.

Since the abatement of what has been termed "double arcing" is the foremost object of this invention, attention shall now be directed to a discussion of known instances of "double arcing" in the prior art. Subsequently, the description will turn to a discussion of the preferred embodiment.

Referring now to FIG. 2 a long arc column forming plasma generator of the prior art, generally designated 38 is shown in a sidewall mounted operating position inside a conventional furnace 39 adapted for melting scrap metals 35. Such a plasma generator as previously stated normally includes a one-piece cylindrical steel housing 37 pysically and electrically connected to the nozzle 14 (shown in cutaway). During normal operation of such a generator the transferred plasma arc will follow an axis generally indicated by dashed line X. Quite often, however, the distance along axis X to a metal scrap may exceed the outer range of the transferred column due to a pocket in the scrap or sudden melting or shifting, for example. When this occurs the arc column is forced to bend slightly as indicated by dashed line Y in order to strike a metallic object within its range. In many cases further bending of the arc column will ensue, with the ultimate result of the creation of a "double arc". A "double arc" in this instance comprises an internal arc 40 extending between internal electrode and nozzle 14, and an external arc 41 extending between nozzle 14 and/or housing 38 and proximate scrap metal 35. Once a "double arc" has been created external arc 41 often creeps rearward to encounter additional proximate metallic scrap as indicated by dashed line 42. Extensive damage to the housing 37 and the nozzle 14 nearly always results.

Referring now to FIG. 3 which shows a second typical case of "double arcing," a plasma column being generated along a normal axis is indicated at Z. Due to electrical connection throughout the scrap 35, current may return back to the generator housing 37 or nozzle 14 by forming an external arc 43 between the housing 37 and a proximate portion of the scrap indicated at 36. Arc 43 being of shorter length than the arc shown at Z may cause the arc at Z to be extinguished and simultaneously therewith may cause an internal arc to form identical with 40 in FIG. 2. Again, substantial damage nearly always results.

Referring now to FIG. 4, a long arc column forming plasma generator of the prior art is generally designated by numeral 41. Mounting of such generator in a furnace 39 has in the past required the use of insulated collars 43, linings and the like in order to prevent grounding of the generator housing 37 against the furnace walls 39'. Such grounding precludes normal operation of the arc circuit, in addition to creating a safety hazard to persons near the mountings. A stainless steel shell 45 has normally housed such insulated collar and retained it within an appropriate mounting aperture 46. A usual problem of such collars 43 when in use for prolonged periods of time is the gradual accumulation of "kish" generally represented by 48. "Kish" is widely known as a particulate substance resembling graphite, comprising carbon, iron and manganese and which often becomes airborne during iron smelting operations. When the accumulated kish 48 becomes sufficient to form an electrically conductive pathway across insulated collar 43, an external arc will form between housing 37 and steel shell 45 and simultaneous therewith the transferred arc T will be extinguished and an internal arc formed similar to that of 40 in FIG. 2. Substantial damage to housing 37 and collar 43 immediately results. A potentially fatal shock hazard also exists to those persons who may accidentally contact the generator during this event.

Continuing with the description referring again to FIG. 1, it is apparent that a long arc column forming plasma generator utilizing a two part housing constructed and insulated in accordance with the first described embodiment is capable of being mounted directly to a furnace aperture without the usual insulated

linings, because the rear housing portion of said generator is insulated at considerable distance (the length of forward housing member **18**) away from nozzle **14**. In addition, housing member **18** being in effect electrically floating prevents current originating in nozzle **14** from being conducted rearward to the generator mountings. Double arcing of the plasma column to the housing, damage and electrical shock hazard caused therefrom are thus effectively eliminated.

While the invention embodiment described in connection with FIG. **1** satisfies the foremost objects of the instant invention it has been recognized that such a plasma generator which employs Synthane insulation or the like to insulate the respective housing members **18** and **19**, is limited to low power and temperature applications due to the degradation of Synthane insulation at extremely high temperatures. Furthermore, while double arcing of the plasma column is substantially prevented from contacting and damaging the housing, double arcing to the nozzle itself has not been abated by providing a two part insulated housing. Finally, this invention contemplates that a one-piece housing, not shown, insulated only a short distance from nozzle **14** would be substantially more susceptible to a "double arc" than would a two piece housing in which two separated external arcs (See **18'** and **19'** in FIG. **1**) would be required to form simultaneously to create a "double arcing" condition. This invention has discovered that the probability of the latter occuring can be reduced even further by water cooling the respective housing members and the probability of double arcing to the nozzle can be diminshed by inducing a non-laminar flow of air across the nozzle face by means of a novel nozzle face configuration.

Referring now to FIG. **5**, the apparatus of the preferred embodiment is directed to a long arc column forming plasma generator as that previously described in connection with FIG. **1**. In the preferred embodiment a two-part housing comprises members **51** and **52**. Each housing member **51, 52** is adapted for cooling by internal manifold structures **60, 61** which form passages **63** for the reception of coolant, e.g., water. Likewise, internal electrode **55** has been adapted by manifold structure **64** for the reception of coolant as indicated at **65**. Since the arc originates internally along a distance of internal electrode **55** indicated by D it is desirable to forceably cool this region especially when the generator is being operated in extremely high power applications. Manifold **64** has therefore been adapted to form a narrower passageway nearest the region designated D of internal electrode **55** than rearward of said region in order to accelerate the flow of coolant, e.g., water over the said critical region. Coolant is adapted to flow through manifold **64** in the directions indicated by arrows **68**. Water cooling of the housing members **51, 52** has the effect of minimizing the possibility of double arcing to the housing due to the reduced surface temperature. Water cooling of the housing members as well as the internal electrode have the added advantage of prolonging the life of the parts in high temperature and power applications. While water cooling of the housing members **51, 52** as well as the internal electrode **55** is regarded as novel in the instant invention, the importance of water cooling of the nozzle **56** has been known in the art for sometime. It satisfies the needs of this invention to state that nozzle **56** is adapted by internal passages, indicated by dashed lines **71**, to receive coolant through conduits **72**. Further elaboration upon the nozzle cooling structure is not deemed necessary herein.

The face configuration of nozzle **56** has been adapted to include a somewhat annular shaped depression **66** formed near the center bore **69**. Said depression has been adapted in the instant invention to prevent the laminar flow of air across the heretofore relatively flat nozzle face during operation of the arc column. Such laminar flow of air is diagramatically indicated by arrows **73, 74** in FIG. **1** wherein nozzle **14** exhibits a face configuration **75** typical of the prior art long arc column forming plasma generators. During operation of the plasma column P, air has been found to flow inward across the flat nozzle face and follow the curvature into the bore **69**. Such flow of air has been found to contribute to internal arcing to the nozzle itself. This invention effectively breaks the laminar air flow by providing the undulations in the nozzle face **76** of the preferred embodiment created by annular depression **66**. Air now tends to circulate within the depression **66** as indicated by arrows **78**. The drastic reduction of the flow of air into the bore **69** appears to enhance vortex stability of the plasma column since internal arcing is noticeably reduced.

A further unique aspect of the invention relates to effectively insulating the various cooperating parts of this invention, i.e., housing members **51, 52** improved nozzle **56** and internal electrode **55** in such a manner as to permit greatly prolonged use of the plasma generator in extremely high temperature and power applications and in the virtual absence of destructive double arcing. In this regard as shown in FIGS. **5** and **6**, cylindrical insulator **81** is adapted to extend partially the length of the plasma generator and is adapted to supportively line housing members **51** and **52**. A second cylindrical insulator **82** is adapted to extend partially the length of the plasma generator to supportively line the outside of the combined internal electrode **55** and water manifold structure **64**. Insulator **82** is also adapted to line the spaces between nozzle **56** and internal electrode **55** which has in the past been lined with an annular insulator (See **21** FIG. **1**) to prevent electrical short circuiting therebetween. Arc gas flow is adapted to bypass insulator **82** of the preferred embodiment and is appropriately ducted through tubes **85** and channels **86**, indicated by dashed lines, provided in nozzle **56**. Insulators **81** and **82** are preferably formed from Synthane material and may be provided with threads **88, 89** for purposes of securement to nozzle **56**. Instead of Synthane material which is available from Synthane Corporation, 1 River Road, Oaks, Pa. there may be employed, e.g., "Delrin" Nylon, made by DuPont, ordinary Nylon or the well-known Westinghouse "Micarta" type insulating materal. Problems have been experienced at high temperatures when the so-called Synthane insulation is exposed to heat. Accordingly, this invention contemplates employing Synthane or like forms of insulation in an enclosed manner by sealing exposed portions of insulator **81** with a so-called Fibrefrax refractory insulation **90**, FIG. **6**. Such an insulating refractory is available from the Carborundum Company, Niagara Falls, NY, in a mortar-like refractory compound which solidifies when heat treated, becomes highly reflective, and will withstand extremely high temperatures. So-called "Ram-90" insulating refractory material made by Har-

binson-walker Company of Pittsburgh, Pa. may also be employed.

Curved recesses **91** are formed between the forward end of housing member **51** and nozzle **56**, best shown in FIG. **6**. Curved recesses **92** are also formed between the opposite end of housing member **51** and the forward end of housing member **52**. Although not shown on the drawing, housing member **52** preferably includes an integral end plate at the rearward end which consequently does not require insulated sealing by the Fibrefrax insulation. It is apparent that insulators **81** and **82** may be formed from many interlocking cylindrical pieces, that nozzle face **76** may employ various alternate configurations and that the invention housing may comprise two or more housing members and still be consistent with the intended breadth and scope of this invention.

Referring specifically to FIG. **6**, is should be noted that the concave recess **91** formed in nozzle **56** resides opposite a convex tip portion **91'** of forward housing section **51** and that the annular void between recess **91** and tip portion **91'** is filled with the insulating refractory material **90**. Such a disposition of mated and spaced curved surfaces between the nozzle and housing eliminates any sharp points of electrical field concentrations on either nozzle or housing, makes the electrical field essentially uniform through the insulating refractory material **90** and thus avoids electrical breakdown between housing **51** and nozzle **56**. Furthermore, the insulating refractory in this configuration is essentially locked into place once it has been heated. The curved recesses **92** act similarly.

With regard to the specific geometry of the nozzle, the teaching of the previously referred to U.S. Pat. No. 3,673,375 is adopted and incorporated herein by reference. The cross sections in particular should be understood as representing annular or cylindrical shapes as the case may be. Using FIG. **4** of that patent as a reference and the designation C for the nozzle internal diameter, the designation B for the nozzle length and the designation A for the nozzle chamber width, the relationship $B/C > 0.2$ for the transferred mode and $B/C \geq 4$ for the non-transferred mode when used in the present invention offers both the advantage of a long arc and freedom from double arcing. Since much of the structure employed in the present invention is shown in U.S. Pat. No. 3,673,375 such patent is also referred to for other mechanical details which were deemed unnecessary to more fully explain in this description.

What is claimed is:

1. In an elongated generally tubular apparatus adapted to generate a long arc high temperature plasma between its discharge end and electrical conductor in an arc circuit which remains substantially free of all but a main arc, in combination:

a. an external tubular thin wall housing formed of a plurality of aligned tubular sections of electrically conducting material including a forward section extending from the discharge end of the apparatus rearwardly, each section including said forward section being electrically insulated from the next rearward section and to the extent that any section provides a point of double arc attachment each such section being further insulated from electrical ground;

b. a fluid cooled cylindrical shaped electrode centrally positioned and supported within said housing and having its forward end proximate the discharge end of the apparatus and its rearward end positioned to receive the usual plasma gas supply therein;

c. a fluid cooled gas directing nozzle axially aligned with, forwardly spaced and insulated from both said electrode and housing forward section, said nozzle with said electrode providing a vortex forming chamber, said nozzle having an internal diameter designated C and a length designated B and with said electrode providing said vortex forming gas chamber of a width designated A, said dimension A being selected as the minimum width at which a vortex strength of 0.25 Mach is obtained when B is of minimum arc sustaining width and C is equal to the internal diameter of said electrode, and B and C having the relationship $B/C > 0.2$ for the transferred mode and $B/C \geq 4$ for the non-transferred mode;

d. gas supply means for introducing an arc gas through said electrode into said chamber to produce a vortical flow in said chamber and nozzle; and

e. cooling fluid supply means for introducing a cooling fluid into said electrode and nozzle to cool the same.

2. An apparatus as claimed in claim **1**, said nozzle having an annular depression formed in the forward end of said nozzle and in a form effective to prevent laminar flow in the space immediately adjacent the forward end of said nozzle and surrounding the plasma generated by said apparatus.

3. An apparatus as claimed in claim **2** wherein selected said housing sections are adapted with cooling passages to be fluid cooled and including means to provide a cooling fluid to such passages.

4. An apparatus as claimed in claim **1** wherein the rearwardmost said housing section is electrically grounded.

5. An apparatus as claimed in claim **1** wherein selected said housing sections are adapted with cooling passages to be fluid cooled and including means to provide a cooling fluid to such passages.

6. An apparatus as claimed in claim **1** wherein said forward housing section and nozzle are shaped to provide opposed spaced oppositely curved surfaces between the forward inner end portion of said forward housing section and the oppositely disposed outer nozzle surface to establish a substantially uniform electrical field between said surfaces and including an insulating refractory material filling the space between said surfaces.

7. An apparatus as claimed in claim **1** wherein said fluid cooled electrode includes fluid cooling passages proximate the forward internal arc generating surface of said electrode formed in a manner adapted to provide a higher rate of heat removal from such surface than from the more rearward internal non-arc generating surface of said electrode.

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