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Muehlberger

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[54] **APPARATUS AND METHOD FOR PLASMA SPRAYING**

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[21] Appl. No.: **372,260**

Related U.S. Application Data

[63] Continuation of Ser. No. 214,584, Jan. 3, 1972, abandoned.

[52] **U.S. Cl.** ..... **219/121 P,** 219/75, 219/76, 313/231

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

[58] **Field of Search** ..... 219/121 P, 74, 75, 76, 219/70; 313/231; 315/111

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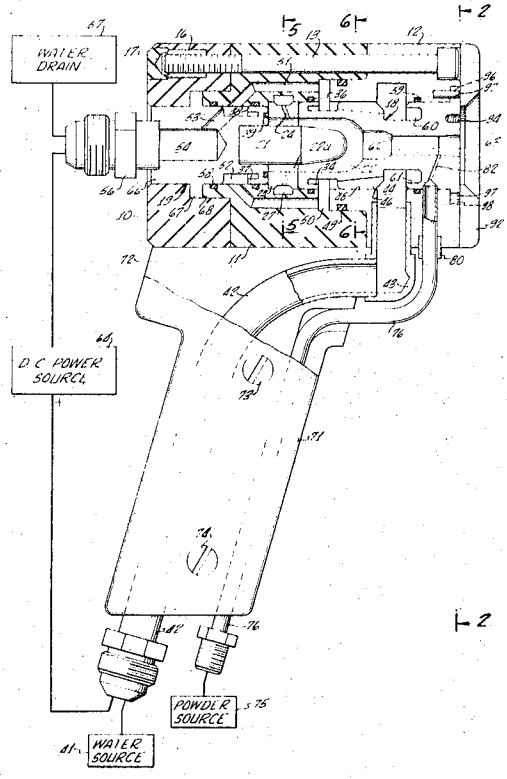
[57] **ABSTRACT**

An extremely high-powered electrical plasma-jet spray torch is constructed economically, safely, and in a compact manner, by use of three coaxial body members held together by longitudinal, internal bolts. No external housing is necessary, the handle being screwed directly onto one of the body members. Two removable electrodes are provided and are separated from each other by a gas-injector ring of heat-resistant insulating material. The electrode ends adjacent the gas injector are water-cooled and are provided with O-ring seals.

Powder is injected into the plasma by use of a rotatable anode adapted to permit selective use of different types of injection, thus vastly increasing the utility of the anode.

In accordance with the method, supersonic flow is employed in combination with very high powers, and plural-port powder injection, to achieve extremely high spray rates.

26 Claims, 7 Drawing Figures



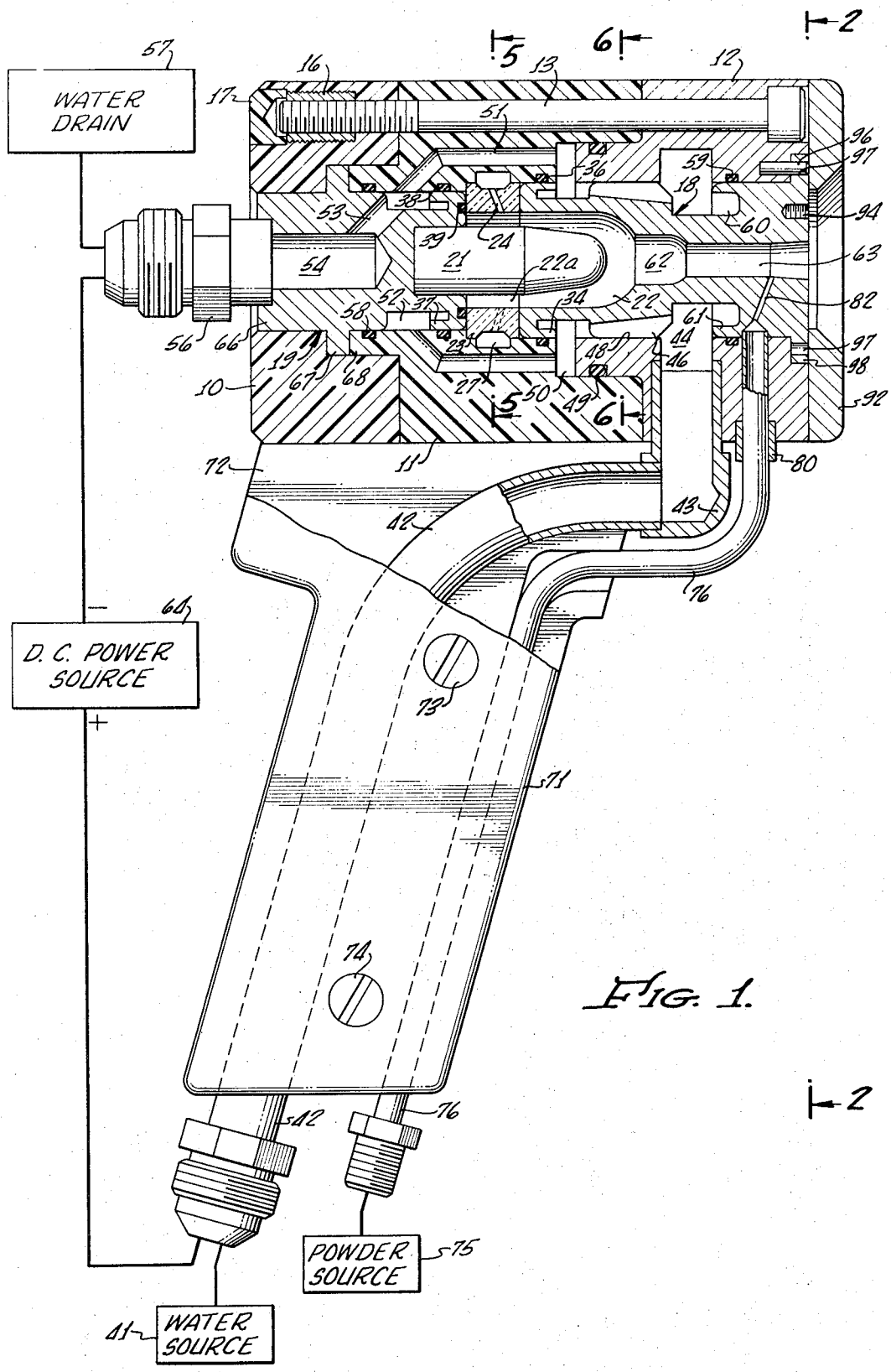
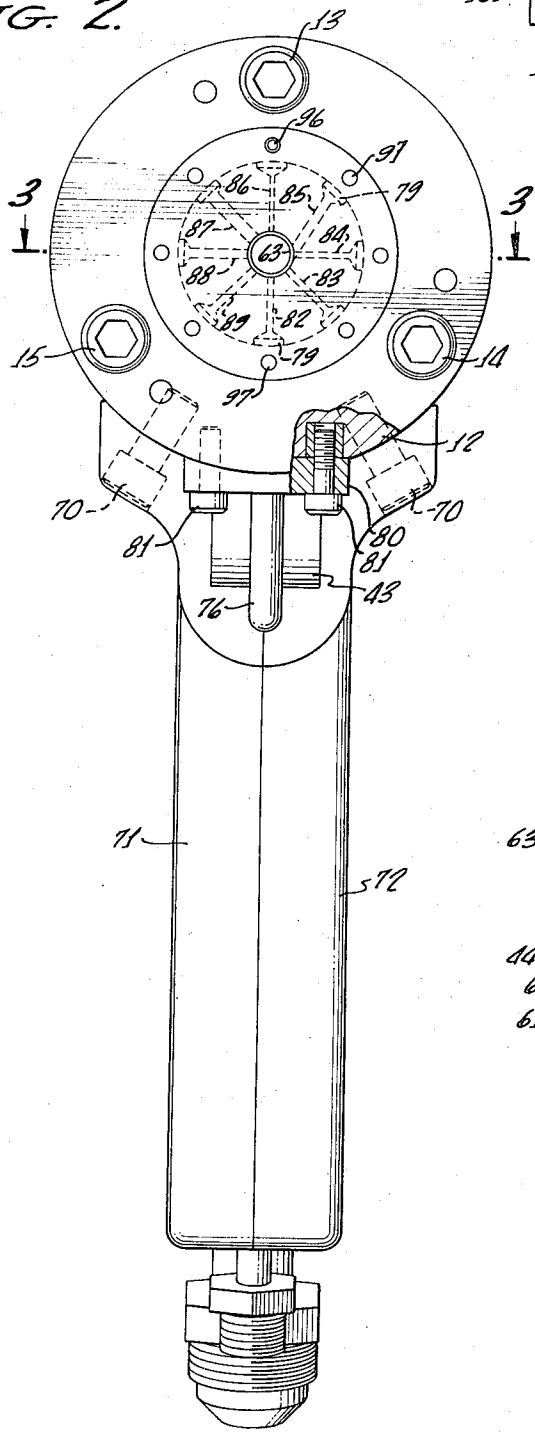


FIG. 1.

FIG. 2.



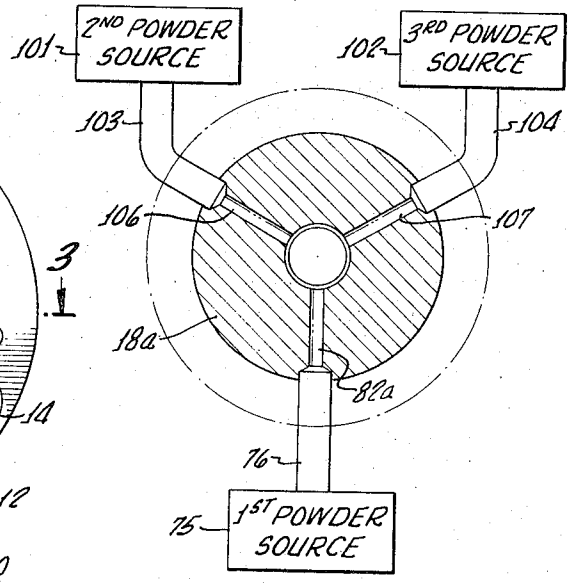


FIG. 7.

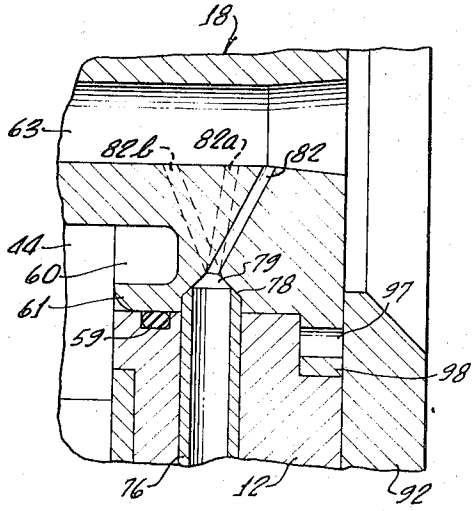


FIG. 4.

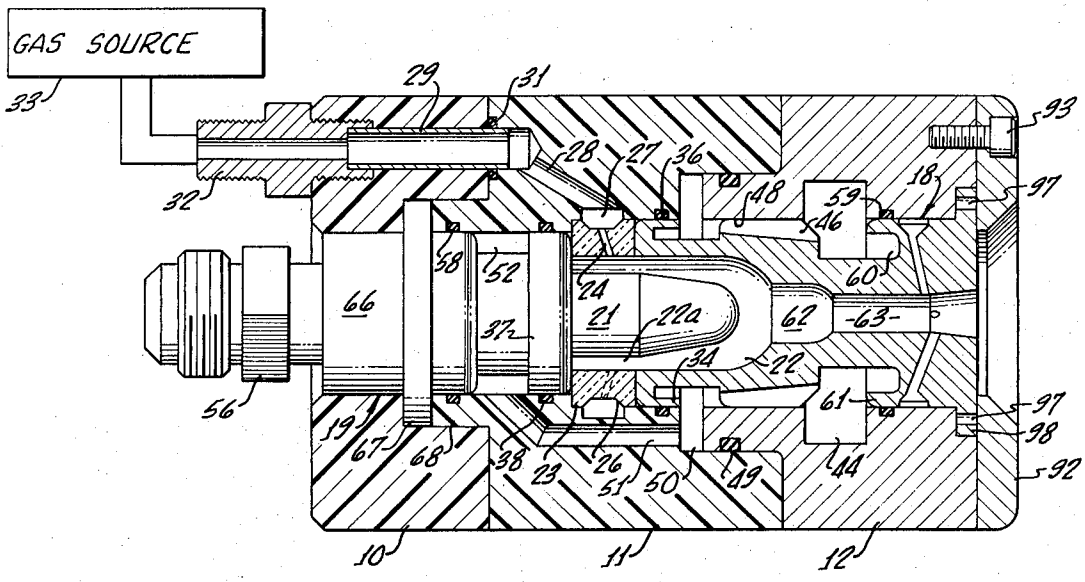


FIG. 3.

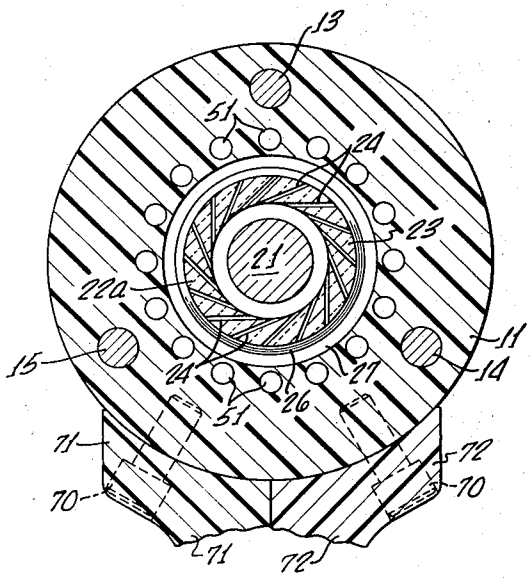


FIG. 5.

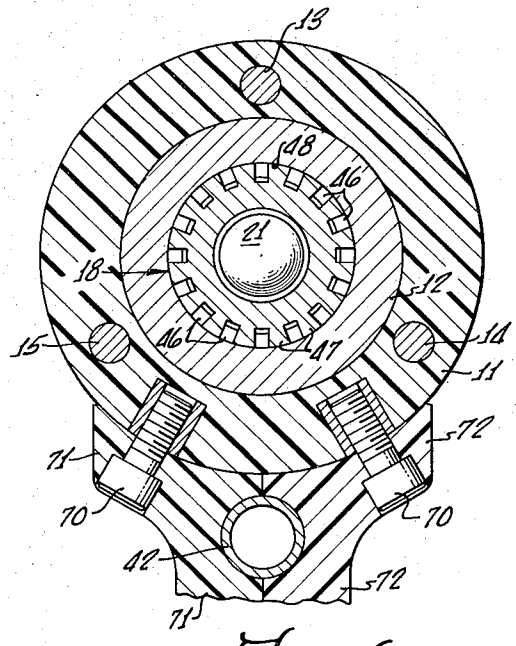


FIG. 6.

APPARATUS AND METHOD FOR PLASMA SPRAYING

CROSS-REFERENCE TO RELATED APPLICATION:

This is a continuation of application Ser. No. 214,584, now abandoned filed Jan. 3, 1972, for Apparatus and Method for Plasma Spraying.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of high-pressure, high-power electrical plasma-jet torches and methods. The invention is particularly directed to the spray coating of substrates by means of such torches.

2. Description of Prior Art

Certain apparatus and methods set forth in my copending patent application Ser. No. 133,126, now U.S. Pat. No. 3,740,522 filed Apr. 12, 1971, for Plasma Torch, and Electrode Means Therefor, and in my copending patent application Ser. No. 143,956 now abandoned, filed May 17, 1971, for Method and Apparatus for Supersonic Plasma Spray, have been sold and/or in public use for more than one year prior to filing of the present application; however, the disclosures of said patent applications are not, per se, prior art against the present application.

Prior art includes the following U.S. Pat. Nos. 2,768,279; 2,943,182; 3,071,678; 3,114,826; 3,118,046; 3,140,421; 3,145,287; 3,179,782; 3,183,337; 3,197,605; 3,205,338; 3,246,114; 3,272,958 and 3,390,292.

SUMMARY OF THE INVENTION

Three coaxial annular body members, two formed of insulating material and one of metal, are held in closely nested relationship by a plurality of internal longitudinal bolts. Into such body members are inserted coaxial anode and cathode means, the cathode means including a stick (rod) electrode which extends into an arc chamber in the anode. The adjacent portions of the anode and cathode means abut an annular gas injector formed of heat-resistant insulating material, and which encompasses the stick electrode. Such adjacent anode and cathode portions are undercut to effect water cooling of O-ring seals which are provided between the electrodes and the intermediate body member. No external housing is required, since a handle means is screwed to the intermediate body member in enclosing relationship to conduit means which conduct water, electricity and powder to the anode means.

The anode means is so mounted in the forward body member that it may rotate about its longitudinal axis. Furthermore, the conduit means which supplies powder to the anode means is adapted to register selectively and sealingly with any one of a plurality of differently-constructed ports, depending on the rotated position of the anode means. Thus, the powder-injection characteristics may be quickly and economically altered as desired.

Extremely high spray rates are achieved by simultaneously employing very high electrical powers, supersonic gas flow, and plural-port powder injection. The present apparatus and method are thus such that a small, safe, compact, high-powered plasma torch achieves surprisingly high spray rates relative to the spray-coating of a substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical sectional view illustrating an electrical plasma-jet spray torch constructed in accordance with the present invention;

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1;

FIG. 3 is a section taken on line 3—3 of FIG. 2;

FIG. 4 is an enlarged fragmentary sectional view showing a lower-right portion of the torch of FIG. 1, and also illustrating in dashed lines various alternative positions for the powder port;

FIG. 5 is a transverse sectional view on line 5—5 of FIG. 1;

FIG. 6 is a transverse sectional view on line 6—6 of FIG. 1; and

FIG. 7 is a transverse sectional view illustrating schematically an embodiment wherein a plurality of powder sources are employed to inject powder into the torch.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring first to FIG. 1, the torch body is illustrated to comprise three annular body members 10, 11 and 12 which are mounted in closely nested relationship relative to each other. The rear body member, numbered 10, is formed of a suitable insulating plastic such as a phenolic. The intermediate body member 11 is also formed of insulating plastic but preferably one which is much stronger, such as a fiber glass-resin composition. Front body member 12 is formed of metal, such as brass.

Each of the annular body members defines an opening therethrough, and the three such openings combine to produce an opening or passage through the torch. Into such torch opening or passage are inserted the anode and cathode means, as described below.

The annular body members 10-12 are maintained in assembled relationship, despite the very high pressure contained therein, by means of three bolts 13–15 (FIGS. 1 and 2) which are oriented longitudinally to the common axis of the body members and are circumferentially spaced 120° from each other. The bolts extend interiorly of the body members, instead of through external flanges or connectors, thereby greatly improving the compactness of the torch.

The head of each bolt 13–15 is recessed into a cylindrical cavity in the forward surface of front body member 12. The threaded rear end of each bolt is threaded into a nut 16 (FIG. 1) which is mounted in a recess in the rear member 10. An insulating plug 17 is cemented into the recess in member 10 to conceal the rear end of each bolt and to prevent the operator from making electrical contact therewith.

It is emphasized that all portions of the torch rearwardly of the metallic front body member 12 are insulating, except for the connection to the cathode means described below. This relationship makes the present apparatus relatively safe to operate.

As shown in FIGS. 1 and 3, the body members 10–12 receive in snug-fitting relationship an anode means 18 and a cathode means 19, the latter having a stick (rod) electrode portion 21 which extends coaxially into an arc chamber 22 in the anode means.

A gas-injector ring 23, formed of a heat-resistant insulating ceramic such as boron nitride, aluminum ox-

ide, zirconium oxide, etc., is mounted between the adjacent or inner end portions of the anode means and the cathode means and in radially-outwardly spaced concentric relationship to the stick electrode portion **21.** More specifically, the cylindrical inner surface of gas-injector ring **23** is flush with the cylindrical surface of the side wall of arc chamber **22,** so that the gas-injector ring and the anode means cooperate to define a gas-vortex chamber **22a** around the stick electrode portion.

Arc gas is introduced into such gas-vortex chamber **22a** through a multiplicity of small-diameter gas-inlet passages **24** (FIGS. **1, 3** and **5**) which are drilled through the gas-injector ring **23.** The illustrated passages **24** are, in the illustrated embodiment, tangentially oriented relative to the gas-vortex chamber **22***a* and, furthermore, incline somewhat forwardly relative to a vertical plane which is perpendicular to the axis of the apparatus. In some instances, however, other types of gas injection may be employed, for example injection which is not adapted to effect vortical flow in the chamber around the stick electrode.

It is an important advantage of the present torch that the manner of arc gas injection may be readily changed, merely by substituting one ring **23** for another. The ring **23** also produces other important advantages, including (a) permitting the vortex chamber **22***a* to be small in diameter, and (b) effectively insulating the anode and cathode from each other.

Gas-injector ring **23** has a rectangular cross section except at the exterior surface thereof, which is provided with an annular groove **26** communicating with the various gas-inlet passages **24.** The ring **23** is seated in a recess or counterbore which is formed in the forward side of intermediate body member **11.** The wall of such recess or counterbore is undercut, at the region radially-outwardly of groove **26,** to provide an annular manifold chamber **27** into which arc gas is introduced through a passage **28** (FIG. **3**). Passage **28** communicates with a recess in intermediate body **11,** and into which a tube **29** is sealingly inserted (there being an O-ring **31**). Tube **29** is soldered to a fitting **32** adapted to be connected to a gas source which is schematically represented at **33.**

It is emphasized that, in accordance with the present apparatus and method, a very large amount of power is "packaged" within a very small space, with consequent enormous generation of heat. For example, in a torch wherein the arc chamber **22** is only about two-thirds of an inch in diameter, the power input may be between 80 kilowatts and 100 kilowatts. The heat-resistant gas-injector ring **23,** particularly since it is spaced rearwardly from the arcing tip of the electrode **21,** is able to withstand the resulting extremely high temperatures. However, means are provided to cool the seals which prevent escape of gas from manifold chamber **27** except through the gas-inlet passages **24.**

The inner end of anode means **18** has a radial flange the rear radial surface of which is abutted against the radial forward surface of gas-injector ring **23.** The flange extends outwardly to a cylindrical element **34** the exterior surface of which abuts an O-ring **36** which is mounted in a groove formed in the interior wall of intermediate body **11.** Furthermore, an undercut is formed between the element **34** and the main body of the rear portion of anode means **18,** into which water flows to thereby maintain O-ring **36** sufficiently cool that it will not deteriorate.

In simiar manner, the forward end of the stick-holder or slug-holder portion (described hereinafter) of cathode means **19** is provided with a radial flange and with a cylindrical element **37,** the latter contacting an O-ring **38** which is seated in the intermediate body. The resulting undercut receives water which maintains the O-ring **38** relatively cool. In addition, an O-ring **39** is mounted in the radial forward surface of the slug holder, in contact with the radial rear wall of the gas-injector ring **23,** being cooled by water present in the undercut in the cathode means.

There will next be described the remainder of the cooling means which maintain the anode and cathode means sufficiently cool that they will not melt or deteriorate excessively, despite the great heat which is generated by the electric arc. Water from a suitable source **41** (FIG. **1**) is caused to flow rapidly through a large-diameter conduit **42** and thence into a right-angle fitting **43** the upper end of which is brazed into a recess in front body **12.** The fitting communicates with an annular groove **44** formed in the front body **12.** From such groove **44,** the water is forced rearwardly through a large number of saw cuts or notches **46** (FIG. **6**) which is defined by teeth **47** extending outwardly from anode means **18** at the region around arc chamber **22.** The teeth **47** are in surface engagement with an interior cylindrical surface **48** of the front body **12,** so that the water is not merely caused to flow around the saw cuts or notches **46** but instead is forced rapidly therethrough in highly efficient cooling relationship to the anode means.

The interior surface **48** is formed on a neck portion of the front body **12,** such neck portion extending rearwardly into a large counterbore in intermediate body **11.** An O-ring **49** is provided to prevent leakage of water out of such counterbore.

The rear end of the neck portion of front body **12** is spaced forwardly from the opposed radial surface of intermediate body **11** at the indicated counterbore, whereby to form an annular chamber **50** into which the water flows after leaving the saw cuts or notches **46.** It is emphasized that the water entering the chamber **50** impinges against the above-described cylindrical element **34** to aid in cooling the O-ring **36** adjacent thereto.

From chamber **50,** the water flows rearwardly through a large number of circumferentially-spaced longitudinal bores or passages **51** in intermediate body **11** (FIG. **5**), such bores having rear portions which incline inwardly and rearwardly to the chamber **52** which is defined in intermediate body **11** around cathode means **19.** The chamber **52** communicates with a plurality (for example, six) of passages **53** which are formed through the cathode means **19** and which communicate with a central passage **54** therein and thus with a fitting **56** leading to a suitable drain **57.**

An O-ring **58** is provided around the cathode means **19** to prevent leakage of water from chamber **52.** An additional O-ring, numbered **59,** is formed around the front portion of the anode means **18** between a cylindrical external surface thereof and an interior cylindrical surface of the front body **12,** forwardly of annular groove **44.** Heating of the last-mentioned O-ring **59** is prevented by water present in an undercut region **60** of the anode means, such region being located radially-

inwardly of a cylindrical portion **61** of the anode means and which abuts the O-ring **59.**

Anode means **18** is a single element made of copper, and which is machined or otherwise formed to contain the various cooling portions described above. The anode means also contains the arc chamber **22** as described, which arc chamber **22** communicates coaxially with a smaller-sized arc chamber or counterbore **62** located forwardly of the rounded tip of the cathode stick or slug **21.** The forward regions of the arc chamber **22** and of the smaller arc chamber **62** are generally rounded or spherical.

The smaller arc chamber **62** communicates coaxially with a nozzle passage **63** having a cylindrical rear portion and a somewhat flared or conical forward portion. The illustrated nozzle passage is of the supersonic type, as is greatly preferred for reasons stated hereinafter, but it may also be subsonic if desired for certain applications. Nozzle passage **63** will not be described in detail since counterparts thereof are set forth in my co-pending patent application Ser. No. 143,956 now abandoned, cited above.

The present spray torch is of the non-transferred arc variety, wherein the entire arc is contained within the torch. Thus, a D.C. power source **64** (FIG. **1**) has the positive terminal thereof connected to conduit **42** (which is formed of copper) to thereby supply D.C. power of positive polarity to the fitting **43** and thus to the front body **12** and to the anode means **18** in contact therewith. The negative terminal of power source **64** is connected to fitting **56** and thus to the cathode means **19.** An electric arc is thus maintained between the tip of the cathode means and the wall of the arc chamber **62.**

Because gas is introduced at high pressure from source **33** (FIG. **3**) through the passage described above, the gas pressure in chambers **22** and **62** is high (for example, 120 psi gauge when the electric arc is present). This high pressure cooperates with the high electric power contained in the torch, and with the characteristics of nozzle passage **63,** in such manner that the flow through the nozzle passage is caused to be supersonic, for example between Mach 1 and Mach 3 (preferably about Mach 2 when spraying is being effected in the atmosphere, as distinguished from being effected in a vacuum chamber).

The present torch may also be employed for cutting purposes, for example by causing the positive terminal of D.C. power source **64** to connect to an electrically conductive workpiece (such as a steel plate to be cut) instead of to the conduit **42.** For cutting purposes, the nozzle passage **63** is preferably shortened, and the electric arc extends clear through the nozzle passage from the stick electrode **21** to the workpiece.

As previously indicated, the cathode means **19** comprises (in addition to the thoriated tungsten slug, stick or rod **21**) a slug-holder or stick-holder **66** having a radial flange **67.** Such flange is seated between the bottom of a recess in rear body **10** and the rear end of a neck **88** on intermediate body **11.** The slug holder **66** is preferably formed of copper.

Referring next to FIGS. **1, 2** and **6** in particular, the torch further comprises handle means which are screwed directly to the torch body by means of the screws **70.** The screws project into inserts in the intermediate body **11,** which (being formed of fiber glass) is very strong. Screws **70** project respectively through the upper ends of first and second handle portions **71** and **72** which are mirror images of each other and abut at the central plane of the torch. Portions **71** and **72** are secured together by bolts **73** and **74** shown in FIG. **1.**

The handle portions **71** and **72** have grooves therein which cooperate to form passages through which the above-described conduit **42** passes, as does an additional tube or conduit **76** adapted to supply spray powder to nozzle passage **63** as described below. Both the conduit **42** and the conduit **76** extend upwardly through the handle and then bend forwardly to a position in advance of the handle, whereupon they bend upwardly into forward body **12** as shown in FIG. **1.**

Powder tube **76** is supplied by a source **75** (FIG. **1**) with spray powder entrained in gas. Such a source is shown in U.S. Pat. No. 3,517,861.

DESCRIPTION OF THE SELECTIVE-PORT POWDER SUPPLY MEANS

The upper end of powder conduit **76** projects slidably through a corresponding radial bore in the lower region of front body member **12.** Furthermore, as best shown in FIG. **4,** the extreme upper end of the powder conduit or tube **76** is beveled at **78** to abut the conical wall of a recess **79** formed in anode means **18.** A cross-member or fitting **80** (FIG. **2**) is rigidly secured to the powder tube or conduit **76** (as by brazing), and is fastened by screws **81** (FIG. **2**) to the front body **12.**

Loosening of the screws **81** permits the operator to shift the upper end of powder tube **76** downwardly and out of the recess **79** (FIG. **4**), thereby permitting rotation of the anode means **18** as described below. Correspondingly, tightening of the screws **81** forces the beveled upper end of tube **76** into recess **79** and effects a seal with the wall of such recess, so that all gas and powder which flow upwardly through the tube **76** pass into the nozzle passage **63.**

Anode means **18** is provided with a plurality, for example eight in the illustration, of such recesses **79** (FIG. **4**), in circumferentially-spaced relationship. Each recess **79** communicates with a port or passage which extends inwardly to the nozzle passage **63.** The various ports or passages are numbered **82–89** in FIG. **2,** and each has at least one characteristic different from that of all the others. Thus, for example, the passages may have different diameters, different inclinations, etc.

As an example, the passage **85** (FIG. **2**) is shown as being tangentially related to the nozzle passage, the relationship being such that the powder is introduced in a clockwise manner as viewed from the front of the torch. This is opposite to the direction of introduction of arc gas through injector ring **23,** this being counterclockwise as shown in FIG. **5.**

Referring to FIG. **4,** the passages **82***a* and **82***b* correspond to passage **82** except that they are inclined at different angles relative to a plane which is perpendicular to the nozzle passage **63** and contains the powder tube **76.** It is pointed out that the three passages **82, 82***a* and **82***b* (FIG. **4**) are not present in the same torch (there preferably being only one port **82,** etc., which communicates with tube **76** at any one time). The passages **82***a* and **82***b* are illustrated herein as alternative angles of powder introduction. Various angles and types of powder introduction are described in my co-

pending application Ser. No. 143,956 now abandoned, cited above.

To cause a selected one of passages **82–89** to register with powder conduit **76,** the upper end of such conduit is lowered by loosening the screws **81** (FIG. **2**) as described above. Thereafter, a front retainer ring **92** (which normally locks the anode means **18** in position) is removed from the front of the torch by removing mounting screws **93** (FIG. **3**) therefor. After the front ring is removed, a threaded tool is inserted into an internally-threaded bore **94** (FIG. **1**) in the forward face of the anode means **18.**

The threaded relationship between the tool and the threads in bore **94** permits the operator to pull the entire anode means **18** forwardly for a fraction of an inch, until there is no longer any engagement with an indexing pin **96** (FIG. **1**) which is permanently and fixedly mounted in the forward face of front body **12** in parallel relationship to the axis of the torch. The pin **96** is selectively received in any one of eight circumferentially-spaced bores **97** which are provided in a flange **98** in anode means **18.** Each bore **97** corresponds in position to one of the conical recesses **79** described relative to FIG. **4.** The flange **98** seats in a counterbore in the face of front body **12.**

Since the indexing pin **96** is no longer inserted in one of the bores **97** after the anode means **18** is pulled forwardly as stated above, the operator may rotate the anode in order to cause the desired one of passages **82–89** to register with the upper end of powder conduit **76.** Thereafter, the anode **18** is pushed rearwardly until indexing pin **96** is again inserted in one of the bores **97,** following which the front ring **92** is mounted in position by means of screws **93,** and following which the screws **81** (FIG. **2**) are tightened to elevate the powder tube **76** and effect a seal at bevel **78** (FIG. **4**) as stated above.

The described rotation of the anode **18** permits a single anode to have a much greater utility than in the prior art, so that various types of powders, various settings of the torch, etc., may be employed with a single anode as necessary in order to achieve maximum spray rates.

DESCRIPTION OF THE METHOD, EMBODIMENT OF FIG. 7

Th method which will next be described, in connection with FIG. **7,** relates to the discovery that the combination of supersonic plasma flow, simultaneous plural-port injection of spray powder, and very high arc power produces spray rates which are surprisingly high. It is emphasized, however, that the arc power must be related to the size of the torch, since the larger torches normally generate arc powers much higher than do the smaller torches.

The torch and method described in my copending patent application Ser. No. 143,956 now abandoned, cited above, discloses supersonic flow but does not disclose simultaneous plural-port powder injection. such prior-art U.S. Pats. Nos. as 3,144,826; 3,183,337; and 3,197,605 teach plural-port powder injection, but only at subsonic flows and relatively low arc powers. U.S. Pats. Nos. 3,179,782 and 3,246,114 purport to teach supersonic flow, and appear ambiguous relative to whether or not there are plural powder ports. It has now been ascertained that if the arc power is extremely high compared to the size of the torch, if plural-port powder injection is employed, and if supersonic flow is employed, then the spray rates increase extremely rapidly.

The method will be described in connection with the present torch, which has (as mentioned above) an arc chamber diameter of about ⅜ inch (chamber **22**). The torch has a nozzle passage diameter of 0.234 inch at the smallest portion thereof, and a nozzle passage length of 0.812 inch.

For a torch of the indicated size, the arc power is in excess of 50 kilowatts, and is preferably in the range of 80 kilowatts to 100 kilowatts. As one illustrative condition, the arc current is 900 amperes and the arc voltage 90 volts.

The pressure of the arc gas (for example, argon) introduced from source **33** (FIG. **3**) is in excess of 50 psi gauge, which produces in arc chamber **22** a gas pressure of 120 psi gauge after the arc is initiated. The combination of the high gas pressure and the high arc power combine with the characteristics of the supersonic nozzle passage **63** to create a supersonic flow through the nozzle and out the torch. The velocity of the plasma emanating from the torch may be about 10,000 feet per second when spraying occurs in the atmosphere. Stated otherwise, the plasma emanating from the torch is in the range of Mach 1 to Mach 3, being preferably about Mach 2 (when spraying is in the atmosphere as distinguished from in a vacuum chamber).

By plural-port powder injection it is meant that separate powder sources are employed simultaneously to feed powder and gas through separate conduits to the nozzle passage **63,** as described below relative to FIG. **7.** It is not preferred to use a single powder source which feeds powder and gas to a plurality of ports.

Referring to FIG. **7,** there is schematically represented a powder source **101** and a powder source **102** which are connected, respectively, to the torch by means of powder tubes **103** and **104.** Such sources **101** and **102** combine with powder from the first source **75** and which is connected through the tube **76** as described relative to FIGS. **1** and **4.**

The powder tubes **103, 104** and **76** communicate, respectively, with powder ports **106, 107** and **82***a* which is provided in the anode means **18***a.*

In the present example, all of the ports **106, 107** and **82***a* correspond to each other in diameter, angle, etc., and all are constructed as shown in FIG. **4** relative to port **82.** It is to be understood, however, that different longitudinal or circumferential positionings may be employed, as well as different angular relationships, etc.

In the present example, and with the torch of the size described above, each port **106, 107** and **82***a* has a diameter (for example) of 1/16 inch. The rate of gas flow from each source **101, 102** and **75** is **50** scfh. The spray coating is thus deposited on a substrate (not shown) at a rate of, for example, 40 pounds per hour.

Except as specifically stated above, the torch of FIG. **7** is identical to the one previously described in detail relative to FIGS. **1–6,** inclusive.

It is pointed out that the anode means **18** may also be regarded as a "nozzle means," since it has a nozzle passage **63** therethrough. Also, the cathode means **19** may be regarded as a "rear electrode means." The front end of slug holder **66** is a "shoulder portion" which extends radially outwardly from stick electrode **21.**

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

I claim:

1. A high-power electrical plasma-jet torch, which comprises:

first body means formed of insulating plastic,

said first body means having a large-diameter central passage therethrough,

second body means formed of metal,

said second body means also having a large-diameter central passage therethrough,

means to mount said first and second body means adjacent each other and with said central passages in mutual alignment to thereby form a continuous passage,

a slug holder formed of metal and inserted into one end of said continuous passage radially-inwardly of said first body means,

an elongated electrode slug having its base end mounted in said slug holder at the inner end thereof,

all portions of at least the forward end of said slug being formed of tungsten,

said slug extending longitudinally of said passage a substantial distance forwardly from the inner end of said slug holder,

said slug having a diameter smaller than that of said inner end of said slug holder,

nozzle means formed of metal and inserted into the other

end of said continuous passage radially-inwardly of said second body means,

the inner end of said nozzle means being spaced longitudinally from said inner end of said slug holder,

the inner end of said nozzle means encompassing said forward end of said slug,

a gas-injector ring formed of heat resistant and electrically-insulating material,

said gas-injector ring being disposed concentrially around said slug between said inner ends of said slug holder and nozzle means,

means to maintain a very high-current electric arc at least part of which is disposed in said nozzle means,

the rear terminus of said arc being at said forward end of said slug,

means to conduct arc gas to and through said gas-injector ring for inward flow around said slug and then forwardly through said nozzle means,

said gas being heated by said arc and discharging from said torch at a high temperature and velocity, and

means to effect cooling of said nozzle means and of said slug holder.

2. The invention as claimed in claim **1**, in which the nozzle passage through said nozzle means is supersonic.

3. The invention as claimed in claim **1**, in which said arc-maintaining means is a D.C. source the negative terminal of which is connected to said slug holder and the positive terminal of which is connected to said nozzle means.

4. The invention as claimed in claim **1**, in which said means to conduct arc gas to said gas-injector ring includes an annular space defined between the outer surface of said ring and a part of said first body means, and further includes circumferentially-spaced passages extending through said ring and communicating with said annular space and also with the space between the inner surface of said ring and the outer surface of said slug.

5. The invention as claimed in claim **1**, in which said first body means comprises two annular components each formed of insulating plastic, and in which said mounting means mounts said two components of said first body means adjacent each other and also adjacent said second body means.

6. The invention as claimed in claim **5**, in which said mounting means comprises a plurality of bolts which extend longitudinally of the torch through said two components of said first body means and also through said second body means, and which maintain the same in closely stacked relationship relative to each other.

7. The invention as claimed in claim **5**, in which said slug holder has a radially-outwardly extending flange which seats between adjacent portions of said two components of said first body means, whereby to maintain said slug holder in a predetermined desired position in said continuous passage.

8. The invention as claimed in claim **1**, in which said inner end of said slug holder has a face which seats against a face at the rear side of said gas-injector ring, and in which said inner end of said nozzle means has a face which seats against a face at the forward side of said gas-injector ring.

9. The invention as claimed in claim **1**, in which an O-ring is provided concentrically around said slug and is seated between said inner end of said slug holder and a portion of said gas-injector ring.

10. The invention as claimed in claim **1**, in which said nozzle means defines a relatively large-diameter arc chamber around said forward end of said slug, and defines a smaller-diameter chamber forwardly of said forward end of said slug, said smaller-diameter chamber receiving the forward terminus of said arc when said arc-maintaining means applies a voltage between said nozzle means and said slug, and in which said nozzle means further comprises a relatively small-diameter nozzle passage extending forwardly from said smaller-diameter chamber.

11. The invention as claimed in claim **10**, in which said last-named nozzle passage is a supersonic passage.

12. The invention as claimed in claim **1**, in which said gas-injector ring is formed of ceramic, and in which said means to conduct arc gas to and through said gas-injector ring comprises a channel defined circumferentially around said gas-injector ring between said ring and an opposed portion of said first body means, and further comprises passages through said gas-injector ring.

13. The invention as claimed in claim **1**, in which said first body means comprises two annular components each formed of insulating plastic and stacked relative to each other, and in which said means to conduct arc gas to and through said gas-injector ring comprises a tube which extends through the outer one of said two components and into a passage in the inner one of said two components, and in which an O-ring is provided around the portion of said tube which extends into said inner one of said two components.

14. The invention as claimed in claim 1, in which said means to maintain said electric arc and said means to effect cooling of said nozzle means and slug holder comprise means to conduct both water and electricity to said slug holder, means to conduct both water and electricity to said second body means and around said nozzle means, and means to conduct water from said second body means through said first body means to said slug holder.

15. The invention as claimed in claim 1, in which means are provided to removably mount said nozzle means in said continuous passage, whereby to facilitate replacement of said nozzle means.

16. The invention as claimed in claim 1, in which said gas-injector ring is formed of a ceramic.

17. The invention as claimed in claim 1, in which a handle is secured by screws to at least one of said first and second body means, and in which no portion of said handle encompasses either of said body means.

18. The invention as claimed in claim 1, in which said means to effect cooling of said nozzle means and slug holder comprises means to conduct water to said second body means circumferentially around said nozzle means, an O-ring disposed circumferentially around said inner end of said nozzle means between said nozzle means and said first body means, passage means extending through said first body means to conduct water from said second body means to an annular recess formed externally in said slug holder, a second O-ring mounted circumferentially around said inner end of said slug holder and seated between said inner end and a portion of said first body means, and means to pass water through said slug holder from said annular recess therein.

19. The invention as claimed in claim 18, in which said inner end of said nozzle means is undercut to receive water from said second body means, whereby to interpose water between said first-mentioned O-ring and said slug, and in which said inner end of said slug holder is undercut to receive water from said annular recess in said slug holder and thereby interpose water between said second-mentioned O-ring and said slug.

20. The invention as claimed in claim 19, in which a third O-ring is provided between a rear surface of said gas-injector ring and said inner end of said slug holder, and third O-ring being cooled by water contained in said undercut in said slug holder.

21. The invention as claimed in claim 1, in which the means to cool said nozzle means comprises a plurality of circumferentially-spaced teeth extending radially-outwardly from said nozzle means and seated against an interior wall of said second means, said teeth being disposed radially-outwardly of the portion of said nozzle means forwardly adjacent said forward end of said slug, means to conduct water to an annular space formed forwardly of said teeth, whereby said water flows rearwardly through the gaps between said teeth, and in which means are provided to conduct water from the rear portion of said second body means to a drain.

22. Th invention as claimed in claim 21, in which an O-ring is provided between said nozzle means and said second body means at the forward portion of said second body means, and in which an undercut is provided in said nozzle means to interpose water between said O-ring and the nozzle passage through said nozzle means.

23. The invention as claimed in claim 1, in which said gas-injector ring includes gas passages so directed as to effect vortical gas flow around said slug.

24. The invention as claimed in claim 23, in which there are a multiplicity of such gas passages, each of small diameter.

25. The invention as claimed in claim 24, in which each of said passages is inclined forwardly relative to a radial plane perpendicular to said slug.

26. The invention as claimed in claim 1, in which said gas-injector ring includes a multiplicity of small-diameter gas flow passages circumferentially spaced therearound.

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