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J. W. WINZELER ET AL

3,183,337

ELECTRICAL PLASMA-JET SPRAY TORCH AND METHOD

Filed June 13, 1961

2 Sheets-Sheet 1

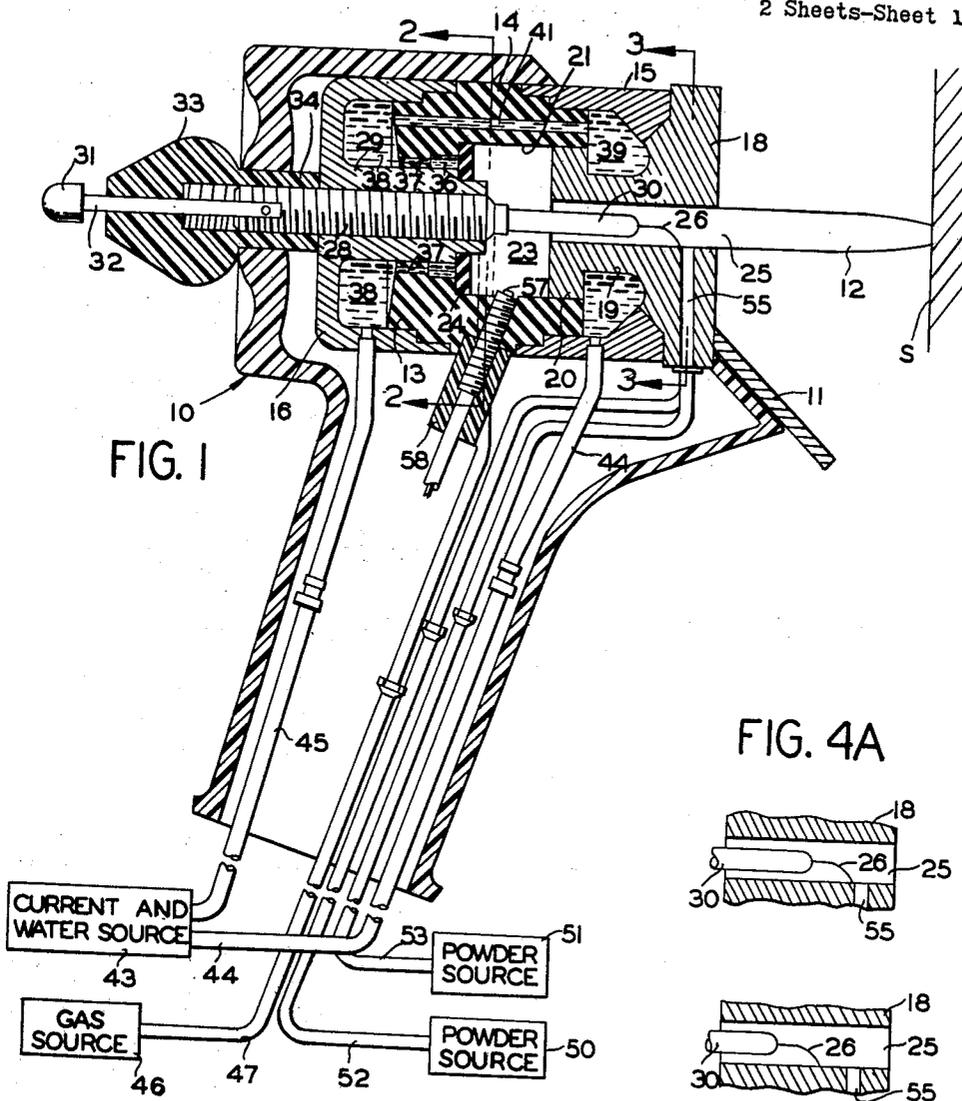


FIG. 1

FIG. 4A

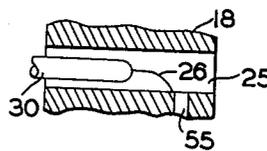


FIG. 4B

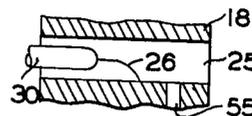


FIG. 4C

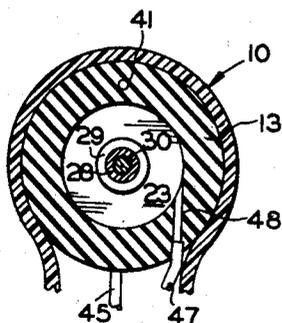
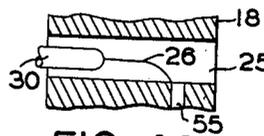


FIG. 2

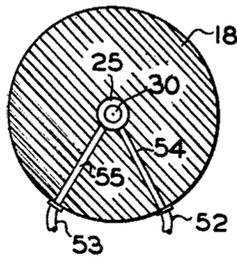


FIG. 3

INVENTORS  
JOHN W. WINZELER  
JAMES F. TUCKER

BY *Richard K. Gurney*  
ATTORNEY

May 11, 1965

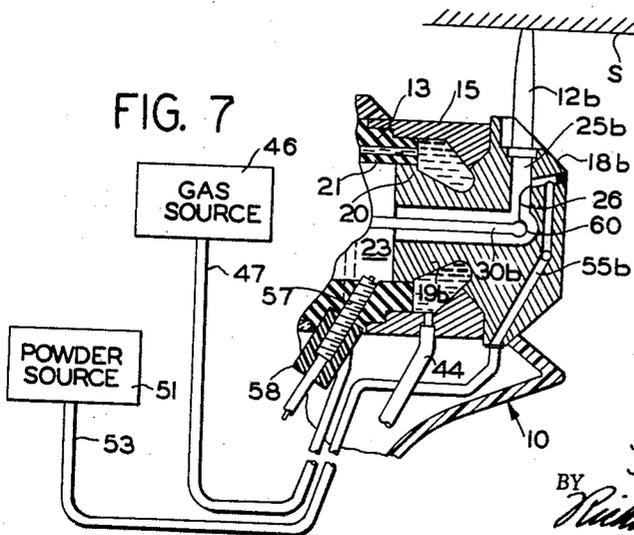
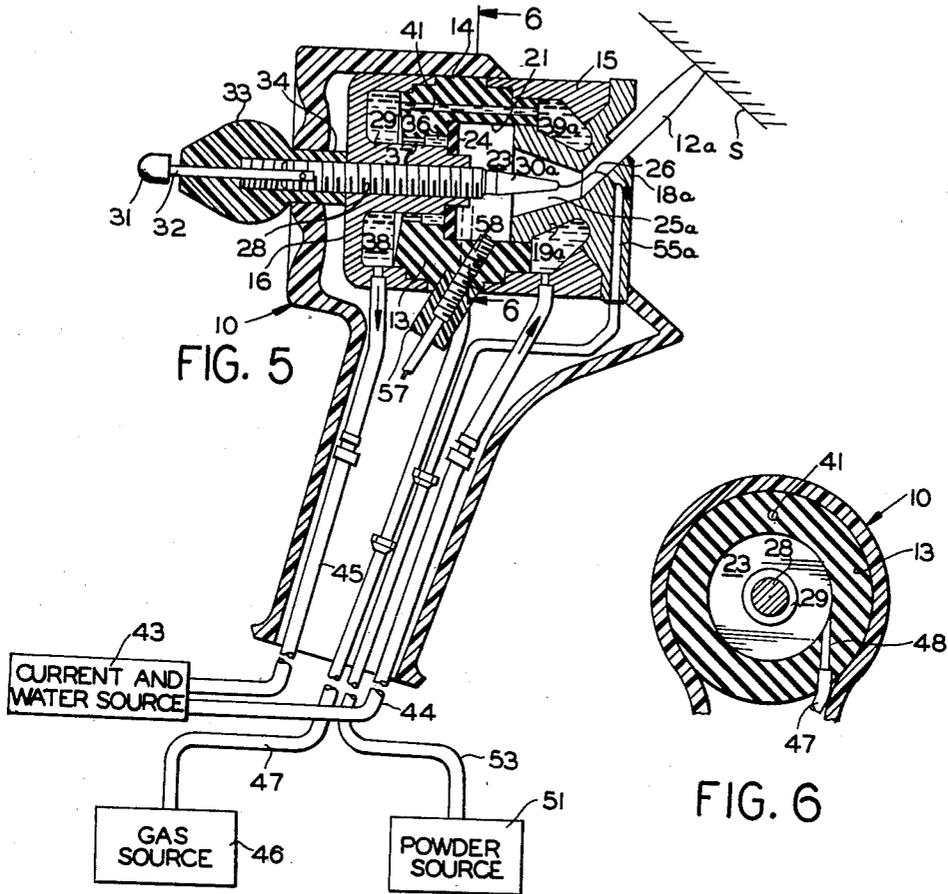
J. W. WINZELER ETAL

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ELECTRICAL PLASMA-JET SPRAY TORCH AND METHOD

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2 Sheets-Sheet 2



INVENTORS  
JOHN W. WINZELER  
JAMES F. TUCKER  
BY *Richard A. Gammitt*  
ATTORNEY

**3,183,337**  
**ELECTRICAL PLASMA-JET SPRAY TORCH**  
**AND METHOD**

John W. Winzeler and James F. Tucker, both of Santa Ana, Calif., assignors, by mesne assignments, to Giannini Scientific Corporation, Long Island, N.Y., a corporation of Delaware

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5 Claims. (Cl. 219-76)

This invention relates to an electrical plasma-jet apparatus adapted to spray onto a substrate a wide variety of materials having greatly different melting points. The invention also relates to a method of effecting spraying, including spray-sintering or alloying.

An object of the invention is to provide a method and apparatus for effecting spraying onto a substrate of materials, including metals, ceramics and mixtures thereof, which melt at temperatures ranging from several hundred degrees F. to thirty thousand degrees F.

A further object is to provide a method and apparatus for effecting spray-sintering or alloying of materials, and which is characterized by extremely high deposition rates.

A further object is to provide an apparatus and method for effecting discharge of plasma at an angle, including a ninety-degree angle, to the axis of a plasma-jet torch, without rendering the plasma density disuniform and without resulting in deposition of powder in the torch.

An additional object is to provide a method and apparatus for adjusting the rear electrode of an electrical plasma-jet torch in relation to the powder-introduction port in the front electrode thereof, thereby permitting a single torch to be employed for different gases and for different materials having widely-varying melting points.

These and other objects and advantages of the invention will be more fully set forth in the following specification and claims, considered in connection with the attached drawings to which they relate.

In the drawings:

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

FIGURE 2 is a transverse section taken on line 2-2 of FIGURE 1;

FIGURE 3 is a transverse section taken on line 3-3 of FIGURE 1;

FIGURES 4A, 4B and 4C are fragmentary sectional views illustrating various electrode adjustments to adapt the torch for different materials and different gases;

FIGURE 5 is a central sectional view schematically illustrating an electrical plasma-jet spray torch constructed in accordance with a second embodiment of the invention, wherein the plasma is ejected at approximately a forty-five degree angle to the axis of the torch;

FIGURE 6 is a sectional view on line 6-6 of FIGURE 5; and

FIGURE 7 is a fragmentary sectional view corresponding generally to FIGURE 5 but illustrating a torch wherein the plasma-jet is ejected at approximately a ninety-degree angle to the torch axis.

Referring to the drawings, and particularly to FIGURES 1-4 which relate to a first embodiment of the invention, the spray torch is illustrated to comprise a unitary casing and handle 10 formed of a suitable insulating plastic. The handle portion of element 10 is hollow and is sufficiently large to receive conduits leading from suitable sources of current, water, gas and spray material. The casing is provided with a suitable metal shield 11 between the plasma jet 12 and the handle, such shield serving to protect from the intense heat of the plasma jet the hand of the operator holding the apparatus. The apparatus further comprises an insulating body

13, preferably formed of a suitable plastic such as a phenolic, having a central flange portion 14 the cylindrical outer wall of which abuts the interior cylindrical wall of casing 10. Abutted against the forward surface of flange portion 14 is a front housing element 15 having a generally annular shape. Such element may be formed of brass or other suitable electrical conductor. Abutted against the rear surface of flange portion 14 is the rim of a generally cup-shaped rear housing element 16 which is also formed of brass or other suitable conductor.

A front electrode element 18, which is preferably formed of copper, has its generally disc-shaped forward portion abutted sealingly against front housing element 15. The stem portion 19 of the front electrode extends inwardly toward the rear housing element, having a flanged portion 20 which abuts the inner surface 21 of the phenolic body 13. Such inner surface 21 is cylindrical in shape and defines the outer portion of a vortex chamber 23 into which gas is introduced tangentially as will be stated hereinafter. The front portion of such vortex chamber is defined by stem 19, including its flange 20, whereas the rear portion of the chamber is defined by a disc 24 formed of a suitable insulating material.

The vortex chamber 23 communicates with, and is coaxial with, a nozzle passage 25 which is bored centrally through the nozzle electrode. Such nozzle passage permits discharge of gas from the vortex chamber 23 to the ambient atmosphere and in the form of the plasma jet 12, it being understood that the temperature of the plasma jet depends upon several factors including the location and magnitude of an electric arc 26 which is maintained between the interior wall of nozzle passage 25 and the tip of a rear electrode assembly next to be described.

The rear electrode assembly comprises an externally-threaded adjustment shaft or rod 28 formed of copper or other suitable conductor, such shaft or rod being threaded into an internally-threaded bore through a stem portion 29 of the rear housing element 16. Soldered coaxially at the extreme front end of the threaded shaft 28 is a rear electrode rod 30 preferably formed of thoriated tungsten. The rod 30 has a diameter substantially smaller than the nozzle passage 25 with which it is coaxial, so that the vortically-flowing gas may pass forwardly from chamber 23 to create the plasma jet 12. An insulating adjustment knob 31 is non-rotatably connected through a rod 32 to the rear end of shaft 28, so that turning of the knob 31 operates through the shaft 28 to move the tip of electrode rod 30 either forwardly or rearwardly.

A lock knob 33, preferably formed of a suitable insulating plastic, is internally threaded to mate with the outer end of adjustment shaft 28, and is also bored to slidably receive the rod 32. An inner or stem portion 34 of knob 33 extends slidably through casing 10 and abuts the outer surface of rear housing 16. The lock knob 33, when manually rotated after the electrode position has been adjusted, operates in the manner of a lock nut to prevent rotation of shaft 28. Furthermore, the lock nut jams the threads of elements 28 and 29 tightly against each other to prevent arcing therebetween.

Instead of or in addition to providing the lock knob or nut 33, the threads of shaft 28 may be caused to have a somewhat different or varying pitch (or other characteristic) in comparison to the internal threads of stem portion 29, so that the shaft 28 may not be rotated except with difficulty. Such an arrangement maintains the threads of elements 28 and 29 in close abutment at all times, and insures against arcing therebetween. It follows that adjustment of the shaft 28 and thus of rear electrode rod 30 is rendered possible during operation of the torch.

The stem portion 29 of the rear housing extends through a bore in body 13, and also through a somewhat smaller

opening in disc 24, to the vortex chamber 23. A counter-bore 36 is provided around the stem 29, inwardly adjacent disc 24, and communicates through passages 37 with a coolant chamber 38 which is defined by the interior surfaces of the rear housing element 16 and by the rear radial surface of body 13. A second coolant chamber 39 is defined around the nozzle passage 25 by stem 19 (including its flange 20), by the front edge or rim of body 13, and by the interior surface of front housing 15. The main coolant chambers 38 and 39 communicate with each other through a passage 41 which extends through body 13 radially-outwardly of vortex chamber 23. The passages 37 permit circulation of water from the rear coolant chamber 38 to the annulus formed by counter-bore 36, so that the forward portion of stem 29 is cooled.

Proceeding next to a description of the various supply sources, and associated elements, a suitable source (or sources) of both current and water is indicated schematically at 43. Such source is connected through water-conducting cables 44 and 45 (such as insulating plastic water conduits containing large electrical conductors) to the front and rear housing elements 15 and 16, respectively. Water is thus fed from source 43 to coolant chamber 39 in the front electrode, from which it flows through passage 41 to rear coolant chamber 38 and the associated counterbore 36, after which it discharges through the cable 45 to a suitable drain.

The electricity which passes through cables 44 and 45 can only flow between the electrodes in the form of the arc 26, since the water which flows through passage 41 has a high electrical resistance. Thus, the electrical circuit comprises current and water source 43, cable 44, front housing element 15, front electrode 18, arc 26, rear electrode rod 30, adjustment shaft 28, rear housing element 16, and cable 45 back to source 43. The current source is normally a D.C. source adapted to deliver very large currents at relatively low voltages. The polarity of the source is normally such that nozzle electrode 18 is positive, and rear electrode rod 30 is negative.

A suitable source 46 of gas under pressure is schematically indicated in FIGURE 1, being connected through a conduit 47 to a passage 48 (FIGURE 2) which extends through body 13 and is tangential to the gas vortex chamber 23. Gas is thus introduced from source 46 into the chamber, where it whirls at substantial velocity and then passes forwardly through nozzle passage 25 in a vortical or helical manner around electrode rod 30.

Proceeding next to a description of the means for introducing spray material into the plasma jet 12, this comprises a plurality of powder sources 50 and 51. It is to be understood, however, that more than two such sources (and associated conduits and ports) may be employed. Powder sources 50 and 51 are connected, respectively, to conduits 52 and 53 which extend through the handle portion of casing 10 to passages or ports 54 and 55 (FIGURE 3) in front electrode 18. Passages 54 and 55 communicate to effect gas-constriction of the arc and to result in a single plane perpendicular to the axis of passage 25. Such plane is spaced a short distance from the forward radial surface of electrode 18, the distance being insufficient to result in deposition of spray material in the outer or forward end of passage 25. The passages 54 and 55, at least at their points adjacent passage 25, are substantially radial to the axis thereof. The passages 54 and 55 are close to each other, or separated by only a small angle as shown in FIGURE 3. This minimizes turbulence, and prevents splitting of the plasma jet.

Each of the powder sources 50 and 51 includes a suitable source of propellant gas, and means to mix such gas with the powder, so that the powder is propelled by the gas through the associated conduit and into nozzle passage 25. Thus, for example, the propellant gas in each source may be introduced into a chamber containing spray powder, so that a portion of the powder becomes entrained in the gas and is carried thereby to the nozzle

passage. Instead of or in addition to employing powder sources 50 and 51, wire-feed devices may be employed to introduce consumable wires of spray material into the plasma jet, through passages 54 and 55.

The remaining component of the torch comprises a spark plug element 57 which is threaded or force-fit into phenolic body 13, being illustrated as inclined toward the inner surface of nozzle electrode 18. A lock nut 53 is threaded over the outer portion of spark plug 57 and is adapted to maintain the same in the desired adjusted position. The spark plug cooperates with front electrode 18 in generating a spark in vortex chamber 23, so that the gas therein becomes ionized and may be employed to initiate an arc between electrode rod 30 and the wall of nozzle passage 25. Electric circuitry for accomplishing this result is described and claimed in co-pending application Serial No. 39,709, filed June 29, 1960, for Low-Voltage System for Initiating an Electric Arc, inventor John W. Winzeler.

#### 20 *Method of effecting spraying and alloying and/or sintering with the electrical plasma-jet torch*

In accordance with one of its aspects, the method comprises providing a high-current low-voltage electric arc entirely within a nozzle passage, passing gas through such passage to effect gas-constriction of the arc and to result in generation of a plasma jet, and injecting spray material into the jet at a point downstream from the downstream footpoint of the arc, such material being injected along a plurality of paths. It has been found that if the spray material is introduced into the arc, that is to say upstream from the downstream footpoint of the arc, various undesired results occur, including vaporization of the spray material as distinguished from melting thereof.

Very unexpectedly, it has been found that if spray powder is introduced along several paths into the plasma jet, as distinguished from being introduced along only one path, the rate of powder deposition upon the substrate S is much greater than if even the same amount of powder is introduced along a single path. The reason for this phenomenon is not completely understood, but it is believed that the introduction of a given large quantity of spray powder through a single port in the nozzle requires a flow velocity of powder-propellant gas which is so high that the powder is merely blasted through the jet instead of being properly entrained therein and heated thereby. On the other hand, where one-half the above-indicated large quantity of powder is introduced through each of two ports, the flow velocity of powder-propellant gas may be greatly reduced, so that the powder is not blown through the jet but instead is heated as desired. It is to be understood (as indicated previously) that more than two powder-introduction ports may be employed, the number varying with factors including the desired number of spray components to be introduced.

A plurality of powder sources 50 and 51, or any desired number, are employed as previously indicated. One reason for this is that it has been discovered that if powder is introduced from a single source into an annulus surrounding the nozzle passage, such annulus communicating through a plurality of passages with the nozzle passage, substantially all of the powder will pass through only one of such passages. Thus, unless special powder-passage configurations are employed in the vicinity of the nozzle passage, it is preferred that separate powder sources be employed for the various powder-introduction passages or ports, such as 54 and 55.

In accordance with another and important aspect of the present method, a separate powder is supplied by each of the sources 50 and 51 or by additional sources, not shown. It has previously been the practice, with modern plasma-jet torches of the constricted-arc type, to effect alloying or sintering by mixing powdered ingredients and then introducing them from a single source into the plasma-jet. Applicants have discovered that improved alloying or sintering is achieved, with less diffi-

culty, by causing the mixture to occur in the jet itself instead of in the powder hoppers. Various metals may thus be alloyed or sintered, as well as mixtures of metals and ceramics or the like (cermets).

According to a further important aspect of the method, the rear electrode 30 of the torch is adjusted in relation to the plane of the powder-introduction passages or ports 54 and 55, and in accordance with the following two factors: (a) the gas which is introduced into the vortex chamber 23, and (b) the melting point or points of the powder introduced through passages 54 and 55. When materials having relatively high melting points are being sprayed, the downstream footpoint of the arc 26 is caused to rest immediately adjacent the upstream edges of the passages 54 and 55, that is to say in the plane (perpendicular to the axis of passage 25) of such upstream edges.

The above may be accomplished, regardless of the gas which is employed, by loosening the lock knob or nut 33 and then rotating knob 31 to adjust the axial position of back electrode 30 in relation to the above-indicated plane. For example, when the arc gas is argon, the back electrode is adjusted until its tip is relatively close to such plane, as indicated in FIGURES 1 and 4A. On the other hand, when the arc gas is a gas such as nitrogen, the electrode is retracted to the position indicated in FIGURE 4C, the arc 26 then being longer because of the characteristics of the gas. It is to be understood that helium, hydrogen or other gases, or various mixtures of gases, may also be employed.

The method also comprises adjusting the back electrode 30 rearwardly sufficiently far that the downstream footpoint is located a substantial distance upstream from the passages 54 and 55, for example at the point indicated in FIGURE 4B. This permits the introduction through such passages 54 and 55, etc., of low melting-point materials such as zinc, lead and even soft solder. On the other hand, when the downstream arc footpoint is in the position indicated in FIGURE 4A or 4C, materials such as tungsten carbide, hafnium carbide, zirconium and alumina may be sprayed. In the described manner, and also by adjusting the magnitude of the arc power, and the rate of gas flow, materials melting as low as 200 to 300 degrees F. may be sprayed, while at the other end of the scale the torch will spray any material which melts at a temperature lower than its disintegration temperature. Stated otherwise, the torch range is from 200 or 300 degrees F. up to 30,000 degrees F.

It is an important feature of the apparatus and method that the arc 26 is constricted and stabilized by the vortically-flowing gas, and furthermore that the downstream footpoint of the arc 26 is rotated by the vortically-flowing gas instead of burning in at one point of the wall of the nozzle passage. Also, and very importantly, the vortical gas flow renders much less critical, as compared to axial flow, the requirement that the electrode rod 30 be concentric with nozzle passage 25.

The argon, nitrogen, or other suitable gas (preferably inert) is introduced tangentially into vortex chamber 23 from the gas source 46, through conduit 47. The gas then flows vortically and forwardly around back electrode rod 30 and around the arc 26 to effect constriction and stabilization of the latter along the axis of the passage 25. The downstream portion of the arc bends radially-outwardly and enters the nozzle passage rearwardly of the plane of passages 54 and 55, as indicated in FIGURES 1 and 4.

There will next be given several specific examples which are illustrative of the present apparatus and method. Let it first be assumed that it is desired to spray a refractory material such as aluminum oxide. A typical torch for this purpose (and which may also be employed for the specific examples stated below) has a nozzle passage 25 the diameter of which is one-quarter inch, and a back electrode rod 30 the diameter of which is one-eighth inch. Each of the powder-introduction passages 54 and

55 may have a diameter of one-tenth to one-eighth inch. The arc current is set at 600 amperes, the arc voltage being about 25 volts. Between 0.8 and 1.1 cubic feet per minute of argon (measured at standard temperature and pressure) are utilized as the arc gas, that is to say are introduced through passage 48 from gas source 46. Approximately 0.3 c.f.m. argon propellant gas is used with each of the powder sources 50 and 51. Such powder-propellant gas is passed through chambers containing the powdered aluminum oxide, so that the powder becomes entrained in the gas and is thus injected into the plasma jet 12. The oxide is thus melted and deposits on the substrate S.

As a second specific example, the same torch may be employed to spray tungsten, the current being 500 amperes at about 26 or 27 volts. The flow of arc gas (introduced through passage 48) may be increased slightly, so that it is between 1.1 and 1.2 c.f.m. The flow of propellant gas employed with each powder source 50 and 51 may be increased slightly, to 0.4 or 0.5 c.f.m. Whether the refractory material being sprayed as aluminum oxide or tungsten, or other desired refractory, the axial position of back electrode 30 is so adjusted that the downstream footpoint of the arc is located rearwardly adjacent the plane of passages 54 and 55, as shown in FIGURE 1 and in FIGURES 4A and 4C.

As a third specific example, a cermet composed of aluminum oxide and tungsten may be sprayed. Aluminum oxide is delivered from one of the powder sources 50, and tungsten from the other powder source 51. The current may be intermediate, for example 550 amperes. The rate of propellant gas flow may also be intermediate that of the two previous specific examples, namely 0.35 c.f.m.

#### Embodiment of FIGURES 5 and 6

FIGURES 5 and 6 illustrate a plasma-jet spray torch system which may be substantially identical to that described relative to FIGURES 1-4, except that the electrodes are adapted to cause the arc and the plasma jet to extend at an angle oblique to the back electrode. Corresponding reference numerals have been applied to parts corresponding to those of FIGURES 1-4, whereas modified components have been given reference numerals corresponding to those of FIGURES 1-4 but followed in each instance by the letter "a."

The nozzle passage illustrated in FIGURE 5 is denoted 25a, having a frustoconical portion which is coaxial with the torch axis, and having a cylindrical portion which extends from the small end of the frustoconical portion at an oblique angle relative thereto. The rear electrode 30a is also illustrated as being conical, and projects into the nozzle passage 25a coaxially with the frustoconical portion thereof. The front or nozzle electrode 18a also contains powder-introduction passages such as are indicated at 55a, only one such passage and the corresponding powder source 51 being illustrated.

In performing the method with the embodiment of FIGURES 5-6, the back electrode 30a is so adjusted that the downstream footpoint of arc 26 strikes in the cylindrical (oblique) portion of nozzle passage 25a. Thus, the arc itself strikes around a corner, having its upstream footpoint at the tip of a stick-shaped back electrode disposed axially of the torch, and its downstream footpoint striking to the wall of a passage portion which is oblique to the torch axis.

It has been found to be highly important that the arc itself turn the corner, not merely the plasma, since in the latter instance the plasma density is not uniform, and powder deposition frequently occurs within the torch because of the great loss of energy which results when the plasma is deflected. Stated otherwise, insofar as is known to applicants all prior-art workers have generated plasma by means of an arc, and then deflected the plasma only.

In the present invention, the arc itself turns the corner so that there is no need to deflect the plasma.

It is to be understood that adjustment of the back electrode 30a may be employed to cause the downstream arc footpoint to be moved upstream from the passages 55a, etc., for purposes previously described relative to FIGURE 4B. Furthermore, it is emphasized that the arc gas still follows a vortical or helical path when it flows through the cylindrical (oblique) portion of nozzle passage 25a. Thus, the part of the arc in such cylindrical portion is vortex stabilized, and the downstream footpoint of the arc is rotated as desired and in order to prevent its burning into the wall of the nozzle passage.

The embodiment of FIGURES 5-6 is highly useful in spraying relatively inaccessible surfaces such as at the interiors of rocket nozzles, the interiors of various containers, etc. An interior surface of one such object is indicated at S in FIGURE 5.

#### Embodiment of FIGURE 7

FIGURE 7 illustrates schematically a torch which (except as will be stated) may be identical to that of FIGURES 1-6, but which need not incorporate the adjustable rear electrode. In the embodiment of FIGURE 7, the nozzle passage 25b contains a first cylindrical portion which is coaxial with the back electrode 30b, and a second cylindrical portion which is approximately at a right angle relative to the first cylindrical portion. The back electrode 30b extends axially of the torch, and has a generally spherical tip 60 the center of which is coaxial with the downstream (second) cylindrical portion of nozzle passage 25b. Powder passages, such as at 55b, are provided through the nozzle electrode 18b to inject powder into the downstream (second) cylindrical portion of the nozzle passage.

In the present embodiment, the spacing between the spherical or ball-shaped electrode end and the powder-introduction ports is made such that the arc 26 will strike the nozzle wall at a point upstream from such powder-introduction ports, for the desired gas (such as argon). As in the previous embodiments, the gas is introduced tangentially into vortex chamber 23, such gas flowing vortically or helically around back electrode 30b and in the upstream or first portion of the nozzle passage. The gas continues to flow vortically or helically after it has turned the right-angled corner into the downstream or second portion of the nozzle passage, so that the arc 26 is stabilized by the gas. Also, the downstream footpoint of the arc 26 is rotated as desired.

The result is a plasma jet 12b which extends generally at right angles to the torch axis, and which may be employed to coat a substrate such as is indicated at S.

It is pointed out that the end wall of the upstream cylindrical portion of the nozzle passage is generally spherical, being concentric with the ball 60. Although only one powder source is illustrated in FIGURES 5 and 7, it is to be understood that a plurality are employed for the reasons stated previously relative to the embodiment of FIGURES 1-4. It is emphasized that, in the embodiment of FIGURE 7 as in that of FIGURES 5-6, the arc itself strikes at an angle to the axis of the torch, which is a situation distinctly different from that which occurs when only plasma is deflected after being generated by an arc.

Various embodiments of the present invention, in addition to what has been illustrated and described in detail, may be employed without departing from the scope of the accompanying claims.

We claim:

1. A method of spraying a powder onto a substrate, comprising providing a back electrode, providing a nozzle electrode having a nozzle passage therethrough, said nozzle passage having at least a downstream portion which extends at an angle to the axis of said back electrode, maintaining a high-current low-voltage electric arc gen-

erally longitudinally of said passage between said back electrode and a predetermined portion of the wall of said passage, said predetermined portion of said passage wall being located in said downstream portion of said nozzle passage whereby said arc extends at an angle to said back electrode, effecting flow of gas through said passage and out the outlet end thereof in a manner effecting stabilization and gas-constriction of said arc to a smaller cross-sectional area than it would normally occupy in space, said arc heating said gas to create a plasma jet downstream from said predetermined portion, injecting into said plasma jet through a first material-injection port and at an axial location downstream from said predetermined portion a spray powder adapted to be melted by said plasma jet, and injecting into said plasma jet at generally said axial location and through a second material-injection port a spray powder adapted to be melted by said plasma jet.

2. An electrical plasma-jet spray torch, which comprises a metal nozzle electrode having a nozzle passage therethrough, a metal back electrode having an elongated portion disposed in said nozzle passage radially inwardly from the wall of said nozzle passage, said nozzle passage having at least a portion which extends at an oblique angle to the axis of said back electrode, the tip of said elongated portion of said back electrode being spaced a substantial distance from the outlet end of said nozzle passage, means to effect flow of gas through said nozzle passage around said elongated portion and thence out the outlet end of said nozzle passage, means to maintain a high-current low-voltage electric arc in said nozzle passage between said tip and the wall of said oblique portion of said nozzle passage at a region upstream from said outlet end thereof, whereby said arc is caused to strike around a corner in said nozzle passage, said arc effecting heating of said gas to create a plasma jet which passes out said outlet end of said nozzle passage, means to introduce spray material into said plasma jet at a predetermined point downstream from the downstream footpoint of said arc, and means to adjust said elongated portion of said rear electrode axially of said nozzle passage to thereby vary the spacing between said footpoint and the point of introduction of spray material to thus regulate the temperature of said plasma jet in accordance with the melting point of said spray material.

3. An electrical plasma-jet spray torch, which comprises a metal nozzle electrode having a nozzle passage therethrough, a metal back electrode having an elongated portion disposed in said nozzle passage radially inwardly from the wall of said nozzle passage, the tip of said back electrode portion being spaced a substantial distance from the outlet end of said nozzle passage, means to effect flow of gas through said nozzle passage around said elongated portion of said back electrode and thence out the outlet end of said nozzle passage, means to maintain a high-current low-voltage electric arc in said nozzle passage between said tip of said back electrode portion and a predetermined portion of the wall of said nozzle passage upstream from said outlet end thereof, said arc effecting heating of said gas to create a plasma jet which passes out said outlet end of said nozzle passage, means to introduce spray material into said plasma jet at a predetermined point downstream from the downstream footpoint of said arc at said predetermined passage wall portion, and means to adjust said elongated portion of said rear electrode axially of said nozzle passage to thereby vary the spacing between said footpoint and the point of introduction of spray material to thus regulate the temperature of said plasma jet in accordance with the melting point of said spray material, said means to adjust said back electrode comprising mating threads, and means to prevent arcing across said threads regardless of the axial position to which said elongated portion of said back electrode is adjusted.

4. An electrical plasma-jet torch adapted to discharge plasma at an angle to the longitudinal axis of the torch, which comprises wall means to define a nozzle passage, an elongated back electrode disposed at substantially a right angle to at least a portion of said nozzle passage, said back electrode having an arcing portion at one end thereof and generally on the axis of said nozzle passage, means to maintain an electric arc from said arcing portion of said back electrode through at least part of said portion of said nozzle passage, said arc striking to the wall of said nozzle passage portion, and means to effect flow of gas along said back electrode and thence through said nozzle passage, said gas being heated by said arc to create a plasma jet which emanates from the torch at an angle to said back electrode.

5. An electrical plasma-jet torch adapted to discharge plasma at an angle to the longitudinal axis of the torch, which comprises wall means to define a nozzle passage, an elongated back electrode disposed at an angle to at least a portion of said nozzle passage, said back electrode having a generally spherical arcing portion at one end thereof, said spherical arcing portion of said back electrode being disposed coaxially of a passage which extends at a right

angle to said nozzle passage and communicates therewith at said arcing portion, the end of said last-named passage being generally concentric with the surface of said arcing portion, means to maintain an electric arc from said arcing portion of said back electrode through at least part of said portion of said nozzle passage, said arc striking to the wall of said nozzle passage portion, and means to effect flow of gas along said back electrode and thence through said nozzle passage, said gas being heated by said arc to create a plasma jet which emanates from the torch at an angle to said back electrode.

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RICHARD M. WOOD, Primary Examiner.