

Feb. 14, 1967

M. L. THORPE

3,304,402

PLASMA FLAME POWDER SPRAY GUN

Filed Nov. 18, 1963

2 Sheets-Sheet 1

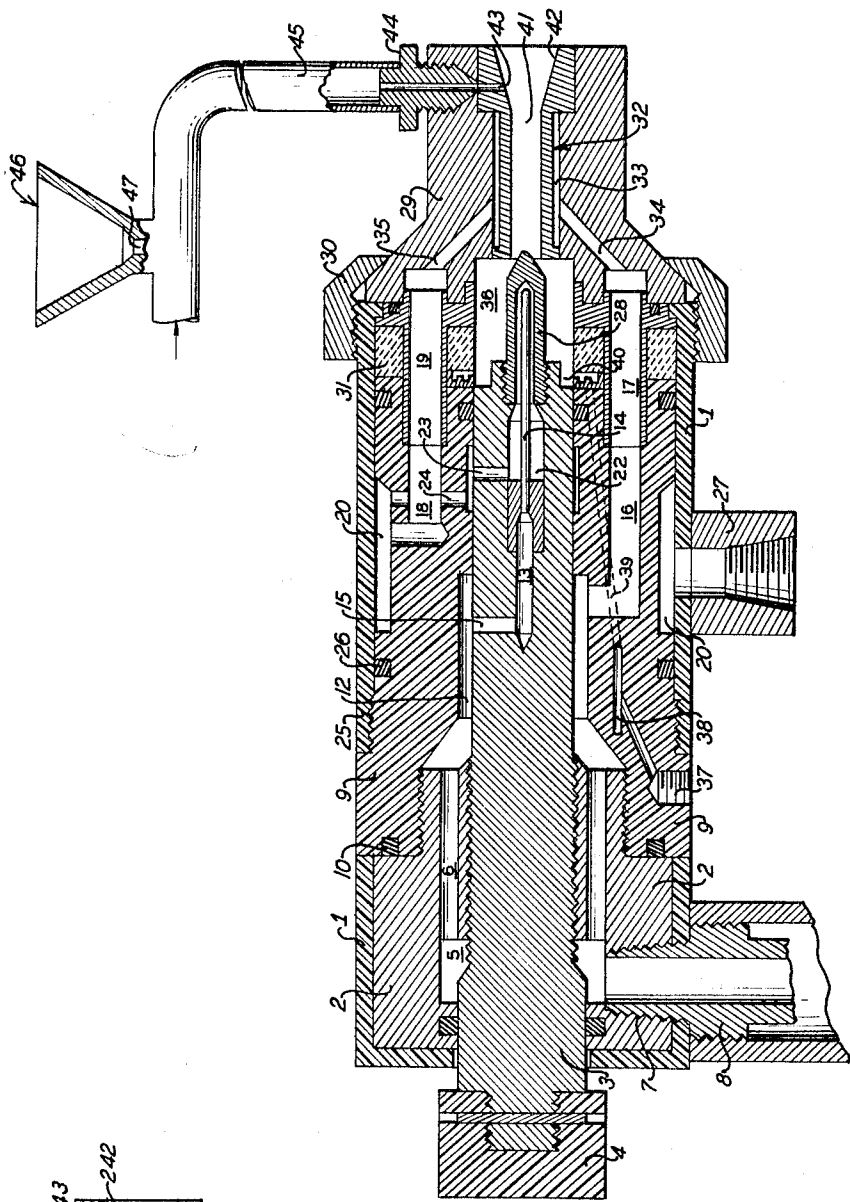


Fig. 1

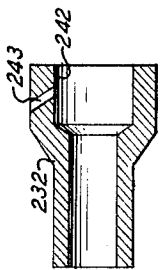


Fig. 2

INVENTOR.
MERLE LEE THORPE
BY
Burgess Dicklage & Sprung
ATTORNEYS

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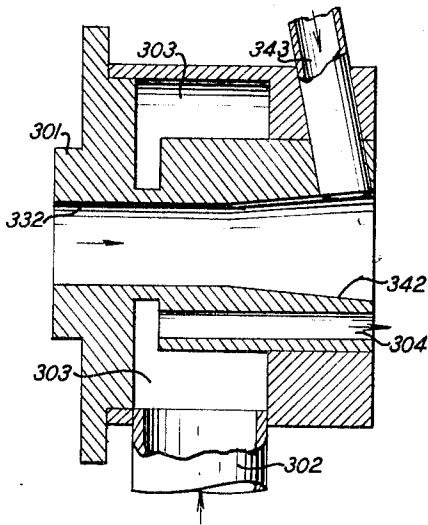


Fig. 3

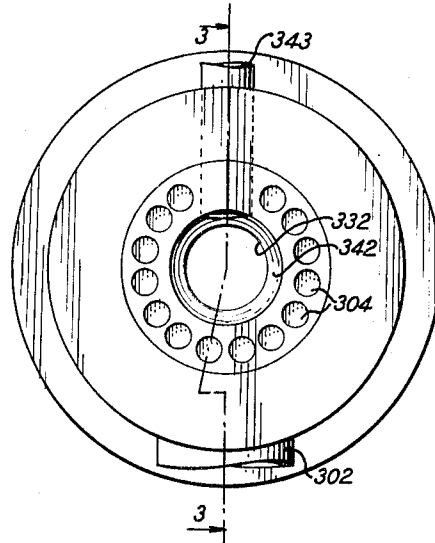


Fig. 4

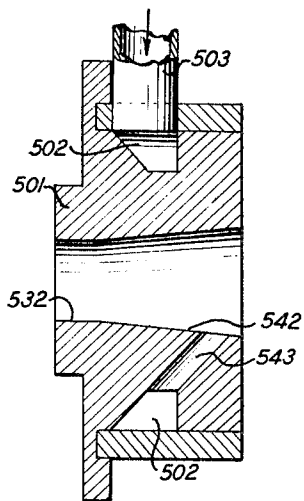


Fig. 6

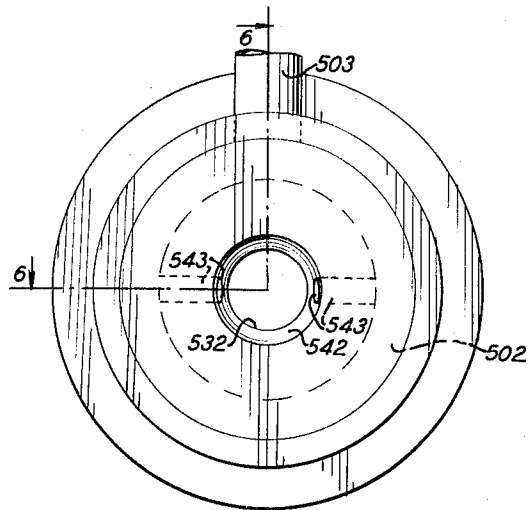


Fig. 5

INVENTOR

MERLE LEE THORPE

BY *Burgess Dickinson Sprung*
ATTORNEYS

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3,304,402

PLASMA FLAME POWDER SPRAY GUN

Merle Lee Thorpe, Suncook, N.H., assignor to Metco Inc., Westbury, N.Y., a corporation of New Jersey
Filed Nov. 18, 1963, Ser. No. 325,520
11 Claims. (Cl. 219-76)

This invention relates to a plasma flame powder spray gun and is a continuation-in-part of my copending application, Serial No. 835,280 filed August 21, 1959 now abandoned.

Powder spray guns are devices in which heat-fusible material, in divided particle form, is fed into a heating zone where the same is melted or at least heat-softened and then blown from the heating zone onto a surface to be coated. The heat-fusible material, in divided form, capable of being sprayed in this manner, is referred to as powder.

The powder to be sprayed is generally fed into the heating zone by means of a carrier gas, and in the heating zone the particles of the material are either melted or their surface heat-softened and then propelled onto the surface to be coated. If the heating is effected by means of a flame, the combustion gases may be utilized for the propelling function. Additionally, a blast gas may be supplied to aid in accelerating the particles and propelling them toward the surface to be coated.

The blast gas may also perform the additional function of cooling the workpiece and the coating being formed thereon.

The heating was most commonly effected with a flame of hot combustion gases produced by the chemical oxidation of a fuel, such as acetylene, propane, coal gas, etc., with oxygen or oxygen in the air.

It is also known to produce the heat by electrical heating means, such as resistance heating, induction heating, or arc heating.

The use of resistance heating is generally confined to crucible type guns where the heating zone is produced in a crucible by means of a conventional resistance heating element. Guns, utilizing this type of heating, however, have only proven suitable for low melting point metals, such as solders, lead and zinc.

Induction heating has never proved successful in concentrating the heat sufficiently to provide a practical heat-fusible spray gun operation.

Electric arcs have only been used successfully to a limited extent. In the usual construction of guns, utilizing wires or rods, these are fed forward at a converging angle while connected to a source of high-amperage, relatively low-voltage electric current so that they ultimately contact each other, striking an arc at a place in the apparatus representing the heating zone. The wires or rods melt in the arc, and the molten metal is atomized by a blast of blast gas and thus propelled toward the surface to be coated.

It has also been proposed to feed the powdered heat-fusible material through electric arcs produced by electrodes made of material other than that being sprayed, such as carbon. In all such cases, the material to be heated is passed directly through the arc flame, the term "arc flame" connoting the stream of electrically ionized particles constituting the path of flow of the electric current forming the arc. It has sometimes been proposed to vaporize the material to be sprayed in the arc flame, rather than merely melting or heat-softening it.

The prior art heat-fusible material spray guns were subject to some very fundamental limitations. All of these guns, except the electric arc construction, were subject to a very distinct limitation on the maximum attainable temperatures. The hottest known, readily avail-

able commercial flame is the oxy-acetylene flame, which has a maximum flame temperature not substantially in excess of about 5,600° F. In practical commercial apparatus, due to this fundamental limitation, it has not been practical to spray materials with melting points above about 5,000° F. While it is true that some chemical flames are known which exceed this temperature limitation of the oxy-acetylene flame, these flames are for some reason or another not commercially practical. For instance, it is known that higher temperatures of almost 9,000° F. may be obtained with the oxygen-cyanogen flame. The cyanogen gas, however, is a deadly poison, extremely explosive, and in any case, the temperature so produced is still a serious limitation for performing many desired heat-fusible material spraying operations.

Arc-type heat-fusible material spray guns, as for example described above, were developed many years ago, and it was first thought that such guns would overcome the temperature limitation of flame type guns in a satisfactory manner. This, however, has not proven to be the case, since it was soon found that arc guns had many inherent limitations of their own and have never proven commercially successful. One of the primary limitations inherent in arc-type heat-fusible material spray guns is that the introduction of the heat-fusible material into the arc flame interferes with the proper operation of such flame in many cases. Where conducting materials are used, such as heat-fusible metals, the introduction thereof in various quantities in the arc flame varies the conductivity of the arc's path, with the result that an unstable arc frequently results.

Unstable arcs may also result from the introduction of non-conducting materials into the arc stream, since such non-conducting solid materials often interfere with the conductivity of the arc stream. Another inherent limitation of such equipment has been the inability to provide a controlled heat for the heating zone, so that for many materials excessive heating results, with a detrimental effect on the heat-fusible materials. As an example, when arc type guns are used to spray carbon steels, the coatings which result are generally hard and brittle, with over-oxidized metallic particles. It has been proposed to overcome this limitation in arc guns with the use of inert gases for blast gas, but the cost of using such gases in the quantities required has been excessive due to the fact that it is usually necessary to blanket the hot particles with inert gas, not only in the heating zone but over their entire path of travel to the surface of the work and even the surface itself, due to the excessive heat imparted from such particles.

In copending application, Serial No. 745,681, filed June 30, 1958, now U.S. Patent No. 2,960,594 of November 15, 1960, a practical apparatus and process is described for producing an entirely novel heating vehicle or media, i.e. a free plasma stream. Plasma is material in an energy state higher than the gaseous state, at least a portion of the atoms of the material being stripped of one or more electrons, which are also present in the free state.

A free plasma stream is defined as a stream of plasma which is free of, and does not constitute a direct part of an electric arc, i.e. does not contribute to the current flow between electrodes.

In copending application, Serial No. 745,680, filed June 30, 1958, now abandoned, an apparatus and process which utilizes a free plasma stream as the media for effecting the thermal conditioning of heat-fusible material to be sprayed and for effecting at least a portion of the propelling function, is described. When, however, the material to be sprayed is in divided particle form, i.e. in the form of a powder, a number of serious problems are encountered.

In order for the free plasma stream to effect the heating and propelling functions, the powder must be conveyed into the same. If it is attempted to introduce the powder entrained in a carrier gas into the center of the plasma stream in the conventional manner used for flame spraying guns, various difficult problems are encountered. Thus, a conduit, such as an introduction pipe, must be provided which extends into the plasma stream. Due to the extreme temperature of the stream, the conduit or pipe will quickly become heated and melted or vaporized. If attempts are made to cool this conduit pipe, for example with water cooling, in order to avoid this difficulty, then the efficiency of the gun drops off rapidly due to the cooling effect on the plasma stream, and the object in the flow pattern of the stream detrimentally affects the same.

An attempt to introduce the powder into the plasma stream from a point outside the stream, adjacent to the stream, introduces a problem with respect to the even distribution of the powder in the stream. In practice powders always contain particles having a certain range of sizes. The force of momentum of the different particle sizes is, of course, different (when the particles travel at the same velocity), so that when introduced from the side of the stream, the heavy particles will carry further into the stream than the lighter particles. If the introduction is so adjusted that the heavy particles will carry to the center of the stream, then the lighter particles will not be carried this far and will concentrate at the fringe of the stream. This may result in the lighter particles arriving at the surface in an unmelted condition. Conversely, if the velocity of introduction of the particles is adjusted, as for example by varying the velocity of the carrier gas stream, so as to force the lighter particles to reach the center of the stream, the heavy particles may have sufficient momentum to pass completely through the stream or only be carried by the outer fringe and thus arrive at the surface in an under-heated condition. In order to obtain high quality coatings with a good deposit efficiency, it is necessary to obtain an even distribution of the particles in the plasma stream, this distribution being at random with respect to variation in particle size. The prior art modes of introducing powdered material into a heating zone or into a gas stream, such as those described above, did not prove satisfactory for this purpose.

One object of this invention is to overcome this problem. This and still further objects will become apparent from the following description read in conjunction with the drawings, in which:

FIG. 1 is a vertical section of an embodiment of a plasma flame powder spray gun in accordance with the invention;

FIG. 2 is a vertical section of an alternate embodiment of a nozzle liner suitable for use in the embodiment shown in FIG. 1;

FIG. 3 is a vertical section of another embodiment of a nozzle construction for a plasma flame powder spray gun in accordance with the invention;

FIG. 4 is a front elevation of the embodiment shown in FIG. 3;

FIG. 5 is a diagrammatic front elevation of a still further embodiment of a nozzle construction for a plasma flame powder spray gun in accordance with the invention; and

FIG. 6 is a vertical section of the nozzle shown in FIG. 5.

The invention is directed to an improved nozzle electrode construction for a plasma spray gun. The spray gun to which the improvement is directed comprises means defining a substantially enclosed chamber, with a nozzle forming an outlet from this chamber. A second electrode, such as a pencil or rod electrode, is at least partially positioned in the chamber in spaced relationship to the nozzle electrode. Means, such as a conventional welding generator, are provided for passing an arc-forming electric current between the electrodes, and means are provided

for passing a plasma-forming gas, for example in the form of a sheath, along the arc and out through the nozzle out of contact with the arc as a free plasma stream, constricting the arc, causing the same to strike part way down the interior of the nozzle prior to its outlet end.

In accordance with the invention the nozzle electrode has a continuous tubular bore of circular cross-section and of constant diameter in the portion in which the arc is struck and constricted, with the outlet end of the nozzle from the portion of constant diameter continuously diverging to a maximum diameter at the nozzle outlet. A powder feed passage is defined laterally through the wall of the nozzle into said diverging portion, past the striking point of the arc, and means are provided for passing a heat-fusible powder through said passage. The term "continuously diverging" as used herein is specifically intended to designate that the cross-sectional area of the nozzle increases toward the nozzle outlet without any subsequent decrease at any downstream point.

Preferably the nozzle is in the form of a continuous cylindrical tube outwardly flared at its outlet end, the flared portion preferably being a conically-flared portion. The side walls of this outwardly flared portion should extend at an angle of about 2-6° and preferably 2½-5° from the nozzle axis, this constituting one-half of the included angle.

The powder feed passage preferably extends through the nozzle wall at a substantial distance from the outlet end of the nozzle, as for example at least an inch from the end thereof, so that the powder will travel a substantial distance through the nozzle before leaving the same.

The plasma flame generator constituting a part of the spray gun to which the improvement in accordance with the invention is directed, may be as described in copending application, Serial No. 745,681, now U.S. Patent 2,960,594 of November 15, 1960.

Very surprisingly the prior art difficulties, including the above mentioned difficulties encountered in the introduction of the powder, are avoided by passing the powder directly into the nozzle having the shape described laterally through its wall and into the diverging portion past the point where the arc strikes.

Referring to FIG. 1, 1 is a casing made of insulating material, as for example synthetic resin, such as polyethylene, nylon or the like. This casing surrounds a body 2 of electrically conductive metal, as for example copper, copper alloy, brass, aluminum, steel or the like. Body 2 has a central female-threaded bore, into which the electrode holder 3 of conductive metal is screwed. The electrode holder 3 has an end adjusting cap 4 of suitable electrical insulating material, as for example synthetic resin or the like. The body 2 also has the annular groove 5 in communication with the bores or conduits 6 and the threaded connection 7, into which the water-cooled current conductor or cable 8 is screwed. Screwed onto the conductive body 2 is the body 9 of insulating material, as for example synthetic resin, such as polyethylene, nylon or the like. The bodies 2 and 9 are sealed to each other by means of the gasket seal 10. The insulating body 9 has a central bore 12 of larger diameter than the electrode holder 3, which surrounds the electrode holder and is flared outwardly at its upper end in flow communication with the bores 6. The electrode holder 3 has at its lower end a central bore or passage 13 in communication with the thin hollow tube 14. The bore 12 is also in communication with the passage 13 by means of the side bore 15. The lower end of the insulating body 9 is provided with the bore 16 in communication with the bore 12 and with a tube or pipe 17 provided as an extension of the bore 16. The lower end of the insulating body 9 is also provided with the bore 18 having the pipe 19 provided as an extension thereof. The bore 18 leads to an annular recess 20 in the insulating body 9. The bore 13 in the electrode holder 3 is widened at 22 around the tube 14

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and provided with a passageway 23-24 leading to the bore 18 and recess 20. A metallic pipe 25, preferably of copper, copper alloy, steel or the like, is fitted around the insulating body 9 in the form of a casing and sealed thereto by means of the O-ring seals 26. The casing 25 is provided with the threaded nipple 27 for connection to a water-cooled electrical cable. The nipple 27 leads into the recess 20.

Screwed into the lower end of the electrode holder 3 is permanent electrode 28, constructed for example of tungsten or thoriated tungsten. The electrode 28 is hollow, and its hollow interior is larger than the tube 14, so that the tube 14 extends down into the interior thereof, leaving annular space between the inner wall of the electrode 28 and the outer surface of tube 14. A nozzle body 29, preferably of the same metal as the casing 25, is secured to the casing by means of the flange 30. A disc 31 of a refractory material, such as an aluminum oxide, is positioned between the nozzle body 29 and the insulating body 9. The disc 31 has openings for the pipes 17 and 19 and is provided with a central bore. The nozzle body 29 has the nozzle 32 fitted therein. This nozzle 32, of platinum, silver or preferably of copper, is soldered in fluid-tight contact with the nozzle body, leaving the annular space 33 therebetween. The annular space 33 is connected on one side with the pipe 17 by means of the bore 34, and on the other side with the pipe 19 by means of the bore 35. The nozzle body and the refractory disc 31 define the enclosed chamber 36, into which the electrode 28 extends.

The insulating body 9 is provided with the female-threaded connection 37 leading into the gas passage 38, which leads to annular gas-distributing grooves 39, which in turn leads into the annular gas outlet space 40 surrounding the electrode 28.

In place of the annular gap formed by the gas-distributing grooves leading into the space 40, a single enclosed groove may be provided into which the passage 38 leads. This groove may be connected to the space 40 by a single or a multiple number of annularly positioned holes. This hole or holes should preferably be positioned at an angle from the center of the axis of the electrode 28, so as to provide a controlled amount of swirl to the gas. The holes may thus be positioned at an angle to the axis of the electrode 28, as for example tangentially, or at an angle of 10 to 30 degrees. In all cases, it is extremely important that an even gas distribution around the electrode be provided.

The end of the electrode 28 has a frusto-conical shape, i.e. a conical shape, the tip of which is flattened, and extends partially into the nozzle 32 which is cylindrical in shape.

The outlet end of the nozzle 32 is conically widened at 42. A passage in the form of a small lateral bore 43 of circular cross-sectional shape extends through the side wall of the nozzle 32. A nipple or bushing 44 is screwed into the nozzle body 29 and has a central bore, which forms a continuation of the bore 43. A flexible hose, such as rubber or the like, 45, is connected to the nipple 44. A powder material feed hopper 46 with the feed orifice 47 is connected to the hose 45. The bore 43 may advantageously be positioned some distance, as for example at least an inch from the outlet end of the nozzle, so that the powder will pass through a length of the nozzle before leaving the same.

In operation water-cooled electrical cables are connected at 7 and 27. These cables are of conventional construction and consist of a metallic electrical conductor surrounded by an insulation-covering provided with cooling-water passages through which cooling water is forced. The cooling-water from the water-cooled electrical cables 8 flows into the annular groove 5 through bores 6 and through the annular passage formed by bore 12. From the annular passage formed by bore 12, a part of the

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cooling water flows through the bore 15, bore 13 and tube 14, to the interior of the hollow electrode 28, cooling the same, and up through annular space around tube 14, out through the passages 23-24 into the bore 18, to the annular recess 20 and out through the water-cooled electrical cable connected at 27 to a suitable drain, or for recirculation. Another portion of the cooling-water from the annular passage formed by bore 12 flows through the bore 16, pipe 17, bore 34, around the annular space 33, cooling nozzle 32, through the bore 35, pipe 19, bore 18, to the annular recess 20 and out through the water-cooled electrical cable with the other portion of the water.

A source of electrical current, as for example from a conventional welding generator or rectifier, is connected to the water-cooled cable 8. This current flows through the conductive body 2 to the electrode holder 3 and then to the electrode 28. The lead of opposite polarity or ground is connected at 27 and is in electrical communication with the nozzle 32 by means of the nozzle body 29 and casing 25.

With cooling-water flowing through the water-cooled leads and the device in the manner described previously, and with a suitable source of current connected at 7 and 27, an arc may be struck between the nozzle 32 and electrode 28, either by screwing the electrode body 3 by means of the insulating cap 4 downwardly to initially strike the arc and by retracting the same by screwing in the reverse direction, or by providing an initial high-frequency source of alternating current connected at 7 and 27. After the arc is struck, the same may be suitably adjusted by screwing the electrode holder 3. Prior to striking the arc, a plasma-forming fluid from a suitable pressure force is passed in at 37, passing through the passages 38-39 to the outlet 40 into the chamber 36. The plasma-forming gas will flow along the electrode 28 over the frusto-conical tip of the electrode and through the nozzle. The plasma-forming gas will form a sheath around the arc between it and the inner surface of the nozzle 32, constricting the arc and forcing the same through the nozzle, as is indicated at 41. The arc is forced down the nozzle so that the same strikes the inner surface of the nozzle prior to its end and prior to the passage 43, so that the passage 43 is positioned between the outlet end of the nozzle and the point where the arc strikes. The plasma-forming gas will be converted in the nozzle to free plasma and leave contact with the arc as a free plasma stream, being projected from the nozzle. The powder material to be sprayed is maintained in the hopper 46, and a small amount of carrier gas is passed through the hose 45. This carrier gas will pick up and entrain the powder passing through the orifice 47 and carry the same through the passage 43. The free plasma stream after leaving contact with the arc 41 will pick up the powdered material and thermally condition and propel the same as it leaves the nozzle at 42. The changes in the flow characteristics and pressure of the plasma stream, as the same passes through the passage 43, will cause a uniform diffusion of the powder throughout the stream, preventing classification and insuring even entrainment and thermal conditioning of the powder in spite of differences in size among the various individual particles of powder. The plasma-forming gas passes into the chamber 36, preferably at a velocity and/or pressure sufficient so that the same will emerge from the nozzle 32 as a free plasma stream having a velocity of at least 5, and preferably at least 50 feet per second, and most preferably at least 500 to 1,000 feet per second.

The free plasma stream generating portion of the apparatus, as may be noted, is substantially similar in structure and operation as described in copending application Serial No. 745,681, now U.S. Patent 2,960,594.

The powdered material to be sprayed may constitute any known or conventional heat-fusible powdered material which could be conventionally sprayed, and may in-

clude materials which heretofore could not be practically or commercially sprayed due to their high melting points or otherwise, as for example tungsten, tungsten carbide free from matrix material, cobalt-bonded tungsten carbide, thoria, calcium zirconate, zirconium carbide and the like.

The particle size of the materials being sprayed may be that conventionally used in the powder spraying art and may vary between about 50 and —325 mesh, and preferably —200 mesh, with fines (smaller than 10 microns) removed.

The amount of carrier gas used is preferably the minimum quantity required to convey the particles material to the passage 43 and depends on the particular construction of the hopper and conveying conduit, which may be as conventionally used in the art. In general, for example, it is an amount of carrier gas of about 0.4 to 5 normal cubic feet (of a gas like N_2) per pound of powder, with a lighter gas, such as H_2 , a corresponding larger quantity should be used.

Most any material in gaseous or in liquid form may be used as a fluid for feeding into the gun as the plasma-forming fluid. Whenever the term "plasma gas," "plasma-forming gas" or a similar expression has been used, it is intended to include the gas of a liquid initially fed into the device, it being understood that such liquid would first be vaporized to form a gas before additional energy would further convert the gas into a plasma.

Any of the known or conventional plasma-forming gases may be used, including those mentioned in copending application Serial No. 745,680, now abandoned. Thus, for example, argon, helium, nitrogen, hydrogen, carbon monoxide and air are among the materials which may be used as the plasma-forming gas.

The end of the nozzle 32, past the point where the arc strikes, need not be conductive and thus may be formed of an insulating material or a different material from the nozzle. It may thus, in effect, form an extension of the nozzle.

The preferable increase in cross-sectional area of the nozzle should at least begin to occur at the point of the passage 43. This increase may occur in any desired manner, as for example a flared increase, conical increase or step-like increase, as shown in FIG. 2 where 232 represents the nozzle, 242 the increased cross-sectional area and 243 the passageway.

As may be noted in FIG. 2, the passage 243 has its axis inclined in the direction toward the nozzle exit.

The velocities required for spraying various materials for obtaining various surface coatings are as conventionally used in the spraying art. Generally, the lower limit gas velocity is about 50 feet per second. If the free plasma stream does not have sufficient energy or velocity to impart spraying velocity to the powder, an additional blast gas stream may be used. In the embodiments shown in FIGS. 3 and 4, provisions are made for this additional blast gas stream. This embodiment is in the form of an extension, which may be provided at the end of the nozzle of a plasma flame generator, as for example described in copending application, Serial No. 745,681, now U.S. Patent 2,960,594. The extension has the body 301, which may for example be constructed of ordinary metal or insulating material, with the bore 332 which corresponds to the bore of the nozzle of the plasma generator. The bore 332 is flared outwardly and is provided with the passage tube 343 for the powder. This passage tube 343 is inclined so that its axis is not normal to the axis of the bore 332, but is inclined toward the nozzle exit. The body 301 has a gas inlet tube 302 leading to the annular passage 303, which is in communication with a ring of annularly positioned gas jets 304. The body 301 is positioned at the end of the plasma generator so that in effect passage 332 forms an extension of the nozzle and is coaxial therewith. The powder is passed in through the

passage 343 in the same manner as described in FIG. 1 and blast gas passed through the tube 302, passing through the annular passage 303 and out of the jets 304. In addition to acting as an additional blast gas, an inert gas may be passed in at 302 to act as an inert gas shield or sheath.

In addition to a single passage for the powder, a multiple number of passages may be provided. When such a multiple number of passages are provided, it is preferable that they be equally spaced around the circumference of the nozzle or nozzle extension and all be directed toward a common point along the nozzle axis and preferably inclined in a forward direction toward this point. Most preferably, two such passages are provided, positioned in a horizontal plane.

Such an embodiment is shown in FIGS. 5 and 6. As shown, a body 501, which forms a nozzle extension in the same manner as the embodiment in FIGS. 3 and 4, is provided. This body has a central bore 532 which corresponds to the nozzle of the plasma generator and is outwardly flared at 542. The body has an annular passage 502, into which a powder feed pipe 503 extends. Two diametrically opposed and forwardly inclined passages 543 extend from the annular passage 502 through the wall of the flared portion 542. These passages are inclined forward and directed at a common point along the axis of the nozzle passage 532.

In operation, the body 501 forming the nozzle extension is positioned at the end of the plasma generator in the same manner as the embodiment in FIGS. 3 and 4, so that the passage 532 forms an extension of the nozzle bore. The extension is preferably so positioned that the passages 543 extend in a horizontal plane, and the powder feed pipe 503 extends vertically. The powder tube, as for example, corresponding to tube 45 in FIG. 1, is connected to 503, and the powder in the carrier gas flows through the annular passage 502 and through the passages 543, being picked up and entrained and propelled by the free plasma stream. With horizontal positioning of the passages 503, the directing of the gun up or down will not affect the relative feed rates of entrained powder through these passages.

The following example is given by way of illustration and not limitation:

Example

A heat-fusible material spray gun, illustrated in FIG. 1, is connected up to two 600 amp. conventional direct current welding rectifiers in series through water-cooled electrical leads, which are also used to supply cooling-water. Cooling-water from an ordinary city water supply at approximately 65° F. is supplied at the inlet end of one of the hollow cables, the other cable being connected to a discharge drain. The gun has the following dimensions:

55	Diameter of electrode 28	inch	0.375
	Included angle of conical electrode tip	degrees	30
	Diameter of flattened end of electrode tip	inch	$\frac{3}{16}$
	Diameter of chamber 36	do	$\frac{3}{4}$
	Length of chamber 36	do	1
60	Diameter of nozzle 32	do	$\frac{7}{32}$
	Length of nozzle 32 to outwardly flared portion 42	do	$1\frac{1}{8}$
	Length of outwardly flared portion 42	do	$\frac{3}{8}$
65	Maximum diameter of outwardly flared portion 42	do	$\frac{1}{4}$
	Distance of passage 43 from nozzle end	do	$\frac{3}{16}$
	Diameter of passage 43	do	.098
	Diameter of hose 45	do	$\frac{3}{16}$
70	Length of hose 45	feet	6

A conventional high-frequency arc stabilizer is connected across the electrical leads in the generator so that a high-frequency igniting current can be imposed on the electrical system by the operator for ignition purposes by closing the switch on the high-frequency generator.

Nitrogen is used for a plasma gas in this case, and is supplied from a bottle source through a conventional pressure-reducing regulator, thence through a conventional flow meter and then conveyed through a rubber hose to the gas inlet of the spraying apparatus. A needle valve is included in the gas line for adjusting the gas flow.

Aluminum oxide powder of a mesh size that will all pass through a 200 mesh U.S. standard screen is placed in the hopper. A compressed air (or N₂) line from a small conventional air compressor (or N₂ bottle) is connected to a needle valve and through a rubber hose to the carrier gas connection of the hose 45 of the spraying apparatus.

A steel plate, about ¼ inch thick and 2 inches square, is given a preliminary preparation for spraying by cleaning and by roughening or blasting with SAE T25 steel grit in a pressure-type blast machine at 90 lbs. p.s.i.

This plate is then placed about 3 inches in front of the outlet nozzle of the spraying apparatus.

The pressure regulator on the nitrogen bottle is set at 50 pounds p.s.i. and the needle valve adjusted to produce a flow of 95 cubic feet per hour (measured at standard conditions). The arc is struck by first setting the welding generator to a current setting of 100 (70 volts) and turning on the switch of the high-frequency generator. Immediately after the arc is struck, the switch on the high-frequency generator is turned off. The flow of current is increased from its initial setting to a final setting of 70 volts and 400 amps.

The needle valve in the carrier gas line is opened somewhat to permit a flow of 10 cubic feet per hour, causing aluminum oxide powder to flow at the rate of approximately 3½ pounds per hour into the plasma jet, passing through the hose 45 and conduit 43. The aluminum oxide is thus sprayed and forms a coating on the plate. The coating is uniform and highly dense, and an examination indicates that the aluminum oxide has been uniformly entrained and propelled by the free plasma stream and no classification has occurred.

In the same manner any of the conventional spray powders may be sprayed.

While the invention has been described in detail with reference to the specific embodiments shown, various changes and modifications which fall within the spirit of the invention and scope of the appended claims, will become apparent to the skilled artisan. The invention therefore is only intended to be limited by the appended claims or their equivalents wherein I have claimed all inherent novelty.

I claim:

1. In a spray gun for spraying divided, heat-fusible material, comprising means defining a substantially enclosed chamber having a nozzle electrode defining an outlet from said chamber, a second electrode at least partially positioned in said chamber in spaced relationship to said nozzle electrode, means for passing an arc-

forming electric current between said electrodes, means for passing a plasma-forming gas along the arc and out through the nozzle electrode out of contact with the arc as a free plasma stream, constricting the arc, causing the same to strike part way down the interior of the nozzle electrode prior to its outlet end, the improvement which comprises said nozzle electrode having a continuous tubular bore of circular cross-section and of constant diameter in the portion in which the arc is struck and constricted, the outlet end of said nozzle electrode from said portion of constant diameter continuously diverging to a maximum diameter at the nozzle electrode outlet, and a passage having an axis which substantially intersects the axis of the nozzle electrode defined laterally through the wall of said nozzle into said diverging portion past the striking point of the arc, and means for passing heat-fusible powder through said passage.

2. Improvement according to claim 1 in which said nozzle is in the form of a continuous cylindrical tube outwardly flared at its outlet end, the walls of said flared portion forming an angle of about 2-6° with the nozzle axis.

3. Improvement according to claim 2 in which said flared portion is a conically flared portion, with the walls thereof forming an angle of about 2¼-5° with the axis of the nozzle.

4. Improvement according to claim 1 in which said means for passing heat-fusible powder is means for passing heat-fusible powder entrained in a carrier gas.

5. Improvement according to claim 1 in which said passage is inclined in a forward direction.

6. Improvement according to claim 1 including a multiple number of said passages.

7. Improvement according to claim 6 in which said passages are directed at a common point on the axis of said nozzle.

8. Improvement according to claim 7 in which said passages are inclined in a forward direction.

9. Improvement according to claim 1 including two opposed passages positioned in a horizontal plane and directed at a common point on the axis of said nozzle.

10. Improvement according to claim 9 in which said passages are inclined in a forward direction.

11. Improvement according to claim 1 including means for passing a blast gas around the nozzle exit in the direction of the nozzle outlet.

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JOSEPH V. TRUHE, *Primary Examiner*.