219-121. SR

12-14-71 XR 3,627,965

[11] **3,627,965**

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[45] Patented **Dec. 14, 1971**
Continuation-in-part of application Ser. No. 66,106, Oct. 31, 1960. This application Jan. 21, 1966, Ser. No. 522,193

[54] IONIZING METHOD AND APPARATUS

9 Claims, 20 Drawing Figs.

[52] **U.S. Cl.** ..... **219/76,** 219/121 P, 302/49, 239/80
[51] **Int. Cl.** **B23k 9/04**
[50] **Field of Search** ..... 222/55, 82, 383, ; 302/49, 66; 198/37; 214/26; 219/75, 76, 110, 121, 121 P, 120; 239/80; 313/12, 14

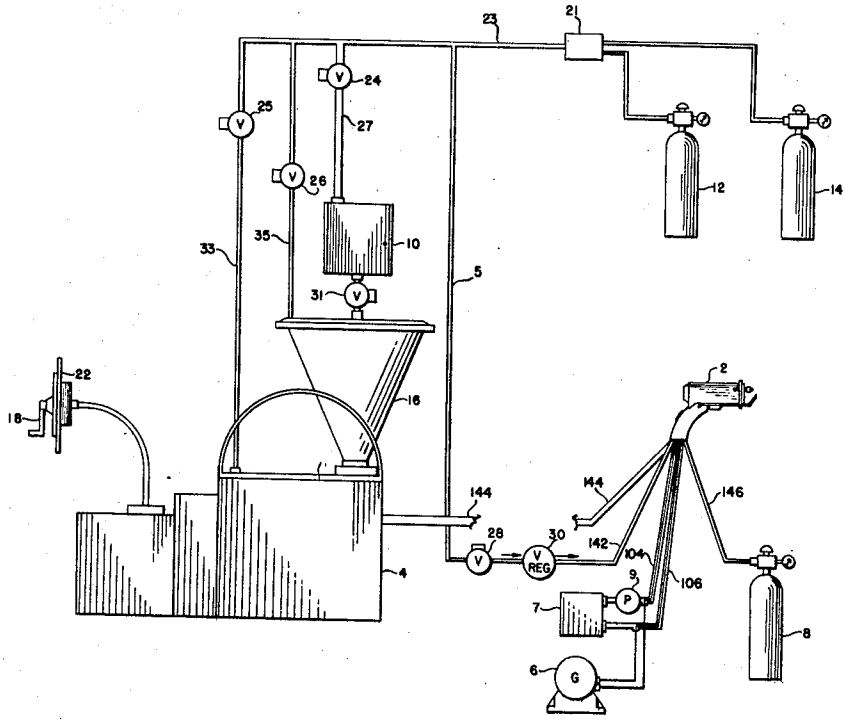
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Primary Examiner—J. V. Truhe
Assistant Examiner—J. G. Smith
Attorneys—William R. Lane, Charles F. Dischler and Harold H. Card, Jr.

ABSTRACT: A plasma gun and powder feed system has purge means for removal of all atmospheric or other matter from the powder feeder, the gun, and inner connecting conduits prior to gun operation. Accurate and automatic flow rate control means are included both for the ionizing gas and the powder feed supply connections to the gun. Oxygen-free purity of powdered materials as received in airtight containers from the manufacturer is thus preserved throughout operation of the plasma-spray system disclosed.



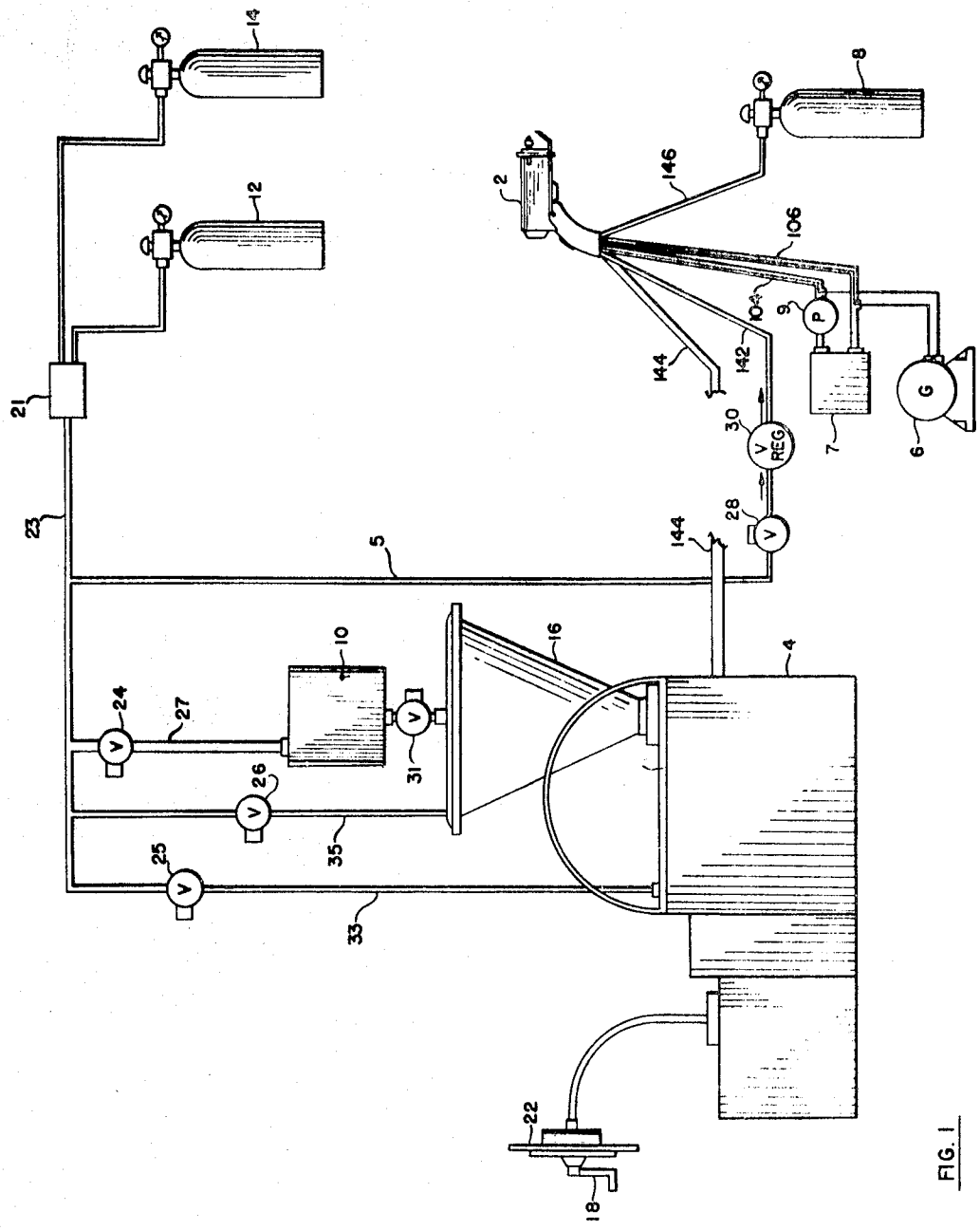


FIG. 1

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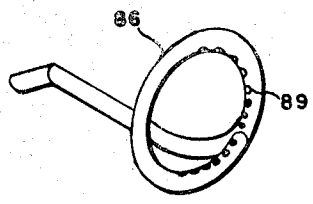


FIG. 14

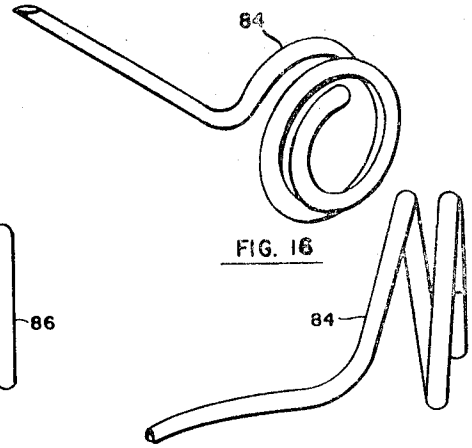


FIG. 16

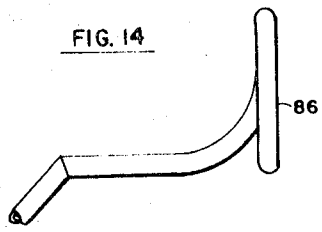


FIG. 15

FIG. 17

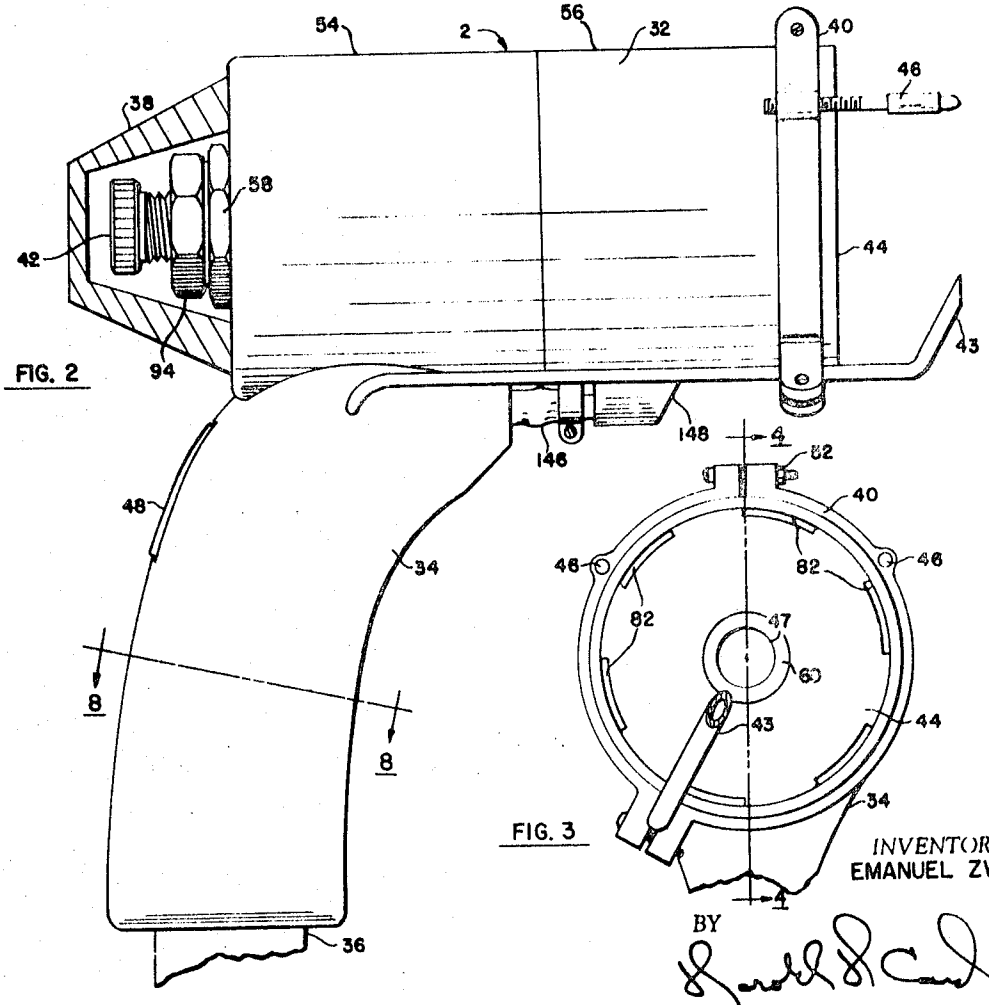


FIG. 2

FIG. 3

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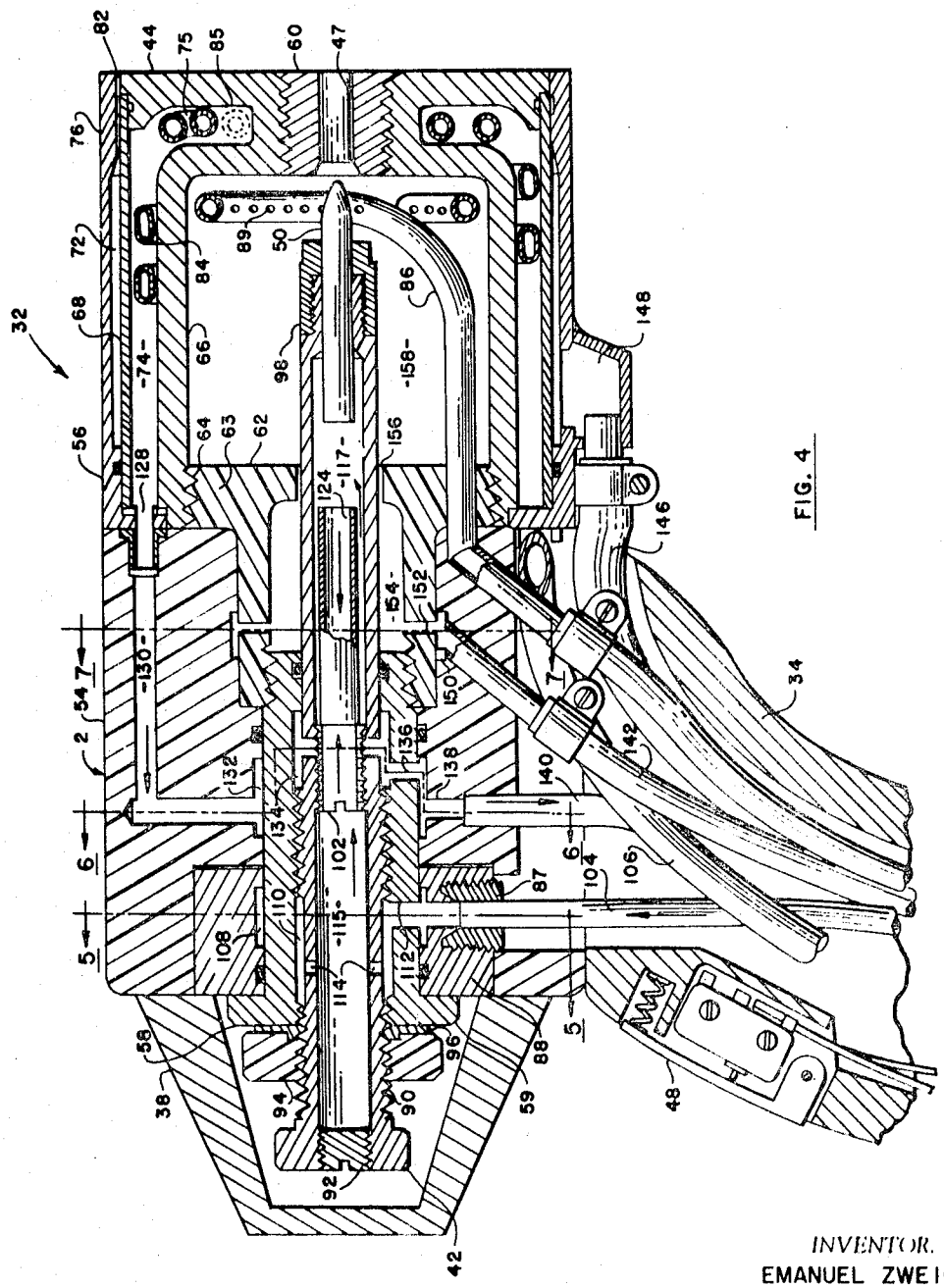


FIG. 4

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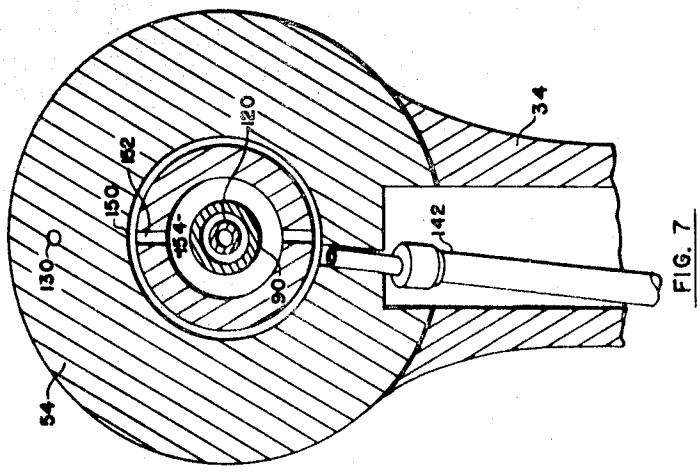


FIG. 7

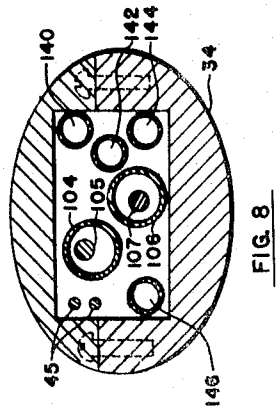


FIG. 8

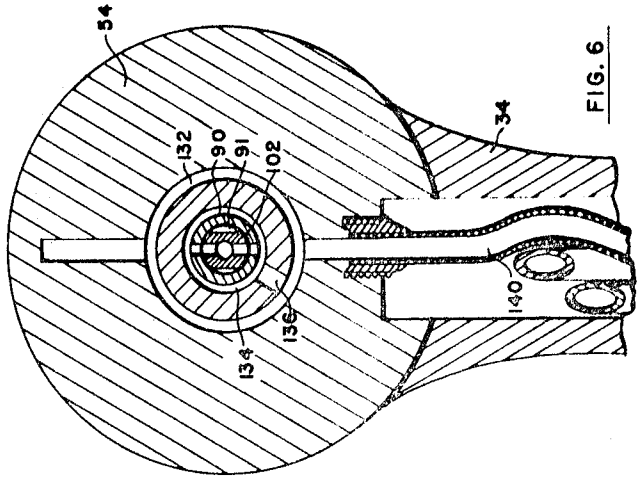


FIG. 6

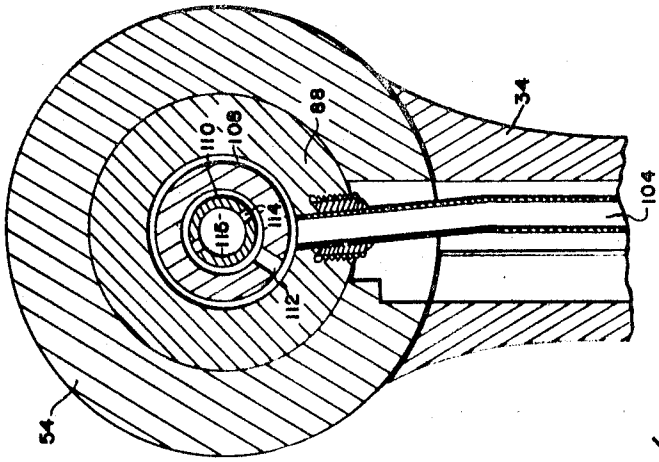


FIG. 5

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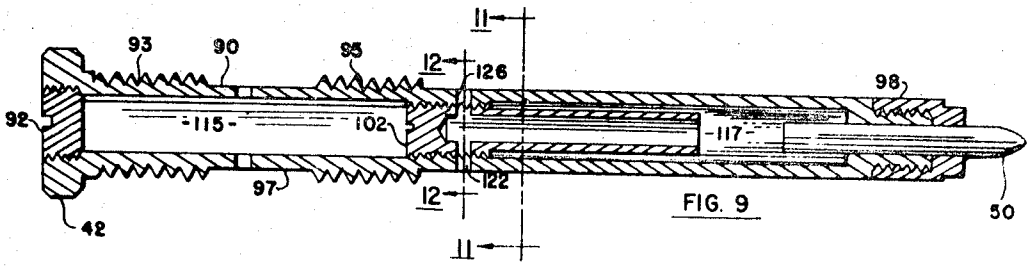


FIG. 9

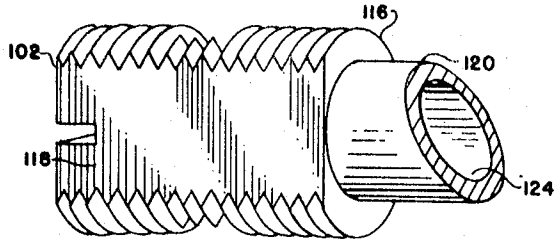


FIG. 10

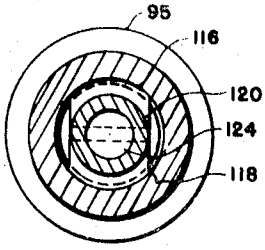


FIG. 11

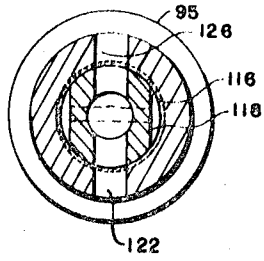


FIG. 12

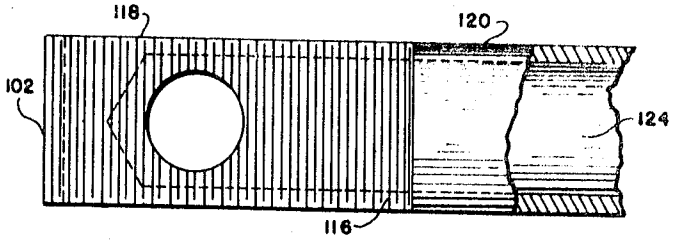


FIG. 13

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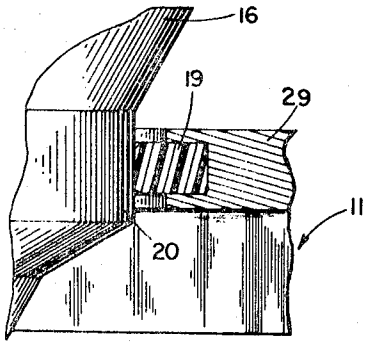


FIG. 19

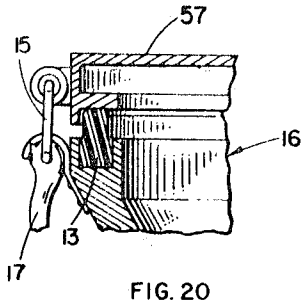


FIG. 20

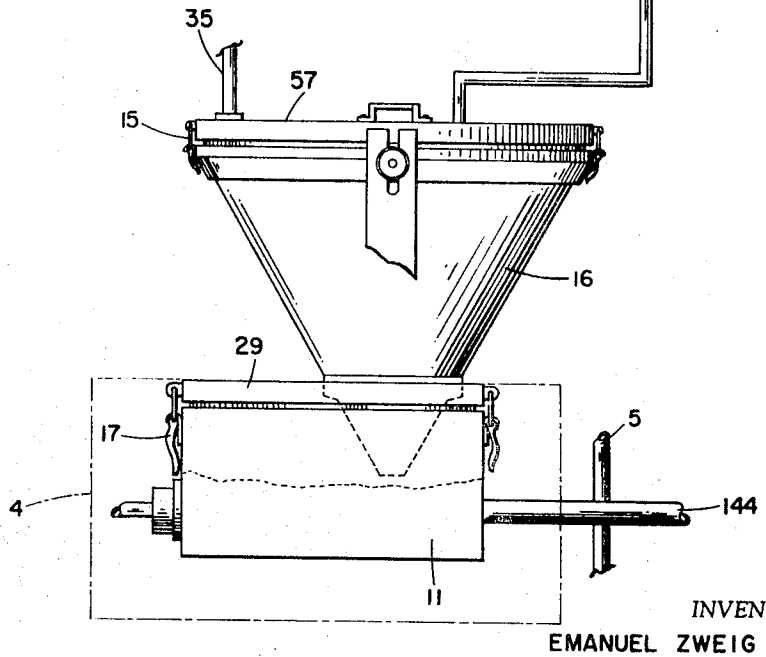


FIG. 18

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IONIZING METHOD AND APPARATUS

This is a continuation-in-part of application Ser. No. 66,106, filed Oct. 31, 1960.

This invention concerns method and apparatus for producing a high-velocity, high-temperature energy source by ionizing a stream of gas. More particularly, the invention contemplates improved method and means for providing a high-energy stream for use either alone or in combination with means for spraying a coating of material upon a surface.

The invention disclosed herein is within the class of devices which broadly comprise electrical arc means for ionizing a stream of gas which may be directed upon a surface, the ionized stream being known generally as plasma. Devices in the stated class may further include means for combining metallic or ceramic material in wire, rod or powdered form with the ionized stream, by means of which the high-temperature metallic or ceramic material and gas mixture may be directed upon a surface to spray or coat the same with such material.

A number of serious disadvantages exist in devices of the stated type known to the prior art, including problems such as rapid and excessive electrode erosion, insufficient cooling of the electrodes and other plasma gun internal parts, lack of temperature control such as required for spraying different materials, and impurities in the plasma. In addition to these, use of plasma coating devices in the prior art is severely limited by the fact that no suitable means of combining metal with the plasma stream has been known previous to the invention disclosed herein. Typical of the problems within this area, use of spray devices having wire feed means commonly results in erratic and incomplete combining of metal with ionized gas, while powder feed systems result in masses of slag or solid metallic particles in the effluent, disrupting the purity and continuity of the sprayed coating or clogging the plasma jet nozzle. In addition, powder feed systems in the prior art are inadequate for use with highly magnetizable metallic powders due to polarity effects of the ionized gas stream, including a repelling effect of the stream upon such powder.

In view of the obvious disadvantages of the prior art plasma jet systems, of which those referred to above are merely illustrative, a critical need exists for an improved plasma jet system capable of providing a relatively pure stream of ionized gas uncontaminated by electrode erosion particles or other impurities. Moreover, a need exists for improved means in a system of the stated type for spraying various different materials with improved continuity and purity. Since the conditions required for effective entrainment of various materials in a stream of ionized gas, and for achieving such ionization, may vary considerably, a versatile plasma jet system would involve suitable means for varying the temperature, pressure or other variables which affect operation of the system. Thus, an additional need exists for means of the stated type.

Accordingly, it is a general object of the instant invention to provide improved method and apparatus for ionizing a stream of gas.

It is a further object to provide improved method and apparatus for obtaining an ionized stream of gas which is relatively free of products of erosion or other impurities.

It is also an object of the instant invention to provide improved electrical means for ionizing a stream of gas with relatively slight electrode erosion.

It is an additional object in this case to provide improved means for ionizing a stream of gas having longer part life and a minimum of wear.

It is a further object of the invention disclosed herein to provide improved method and apparatus for plasma coating a surface with material by combining such material with an ionized stream of gas, including means for preserving the purity of the material coating such surface.

It is also an object in this case to provide means for achieving a coating of material on a surface in a preselected amount, including means for automatically preventing the coating from exceeding such amount.

It is an additional object of this invention to provide improved means for ionizing a stream of gas including means for varying and controlling the temperature of the plasma stream.

Other objects and advantages will become apparent upon a close reading of the following detailed description of an illustrative embodiment of the invention, reference being had to the accompanying drawings wherein:

FIG. 1 shows in schematic form a general view of the novel ionizing system disclosed herein,

FIG. 2 shows a side elevation of the plasma gun included in the system of FIG. 1,

FIG. 3 shows a front elevation of the plasma gun of FIG. 2,

FIG. 4 shows a cross-sectional view through the plasma gun of FIGS. 2 and 3 taken on line 4—4 of FIG. 3,

FIGS. 5, 6 and 7 are cross-sectional views through the plasma gun of FIGS. 2 and 3 taken on lines 5—5, 6—6, and 7—7, respectively, indicated on FIG. 4,

FIG. 8 is a cross-sectional view through the plasma gun handle taken on line 8—8 of FIG. 2,

FIG. 9 is an isolated cross-sectional view of the cathode holder shown in FIG. 4,

FIG. 10 is a perspective view partly broken away of the cathode coolant orifice member contained within the cathode holder of FIG. 9,

FIGS. 11 and 12 are cross-sectional views taken along lines 11—11 and 12—12, respectively, indicated on FIG. 9,

FIG. 13 is a plan view, partly broken away, of the structure shown in FIG. 10,

FIGS. 14 and 15 are isolated perspective and side elevational views, respectively, of the powder feed manifold in the structure shown in FIG. 4,

FIGS. 16 and 17 are isolated perspective and top plan views, respectively, of the anode coolant manifold in the structure shown in FIG. 4,

FIG. 18 is a fragmentary isolated view of certain components from the feeder system shown in FIG. 1, but with slightly greater detail and with portions of structure omitted for the sake of clarity, and

FIGS. 19 and 20 are fragmentary views of seal details in the feeder shown by FIGS. 1 and 18.

With reference to the drawings described above, and particularly to FIG. 1, it may be seen that the novel ionizing system disclosed herein includes portable ionizing chamber means in the form of plasma gun 2, which through appropriate supply lines receives the several elements required to accomplish the ionizing process within the gun. Thus, powder supply means are provided in the form of feeder 4 which may receive metallic powder from magazine 10 through hopper 16. Each of the stated components 4, 10 and 16 also may receive a mixture of inert gases from sources 12 and 14 through manifold 21, and supply line 23 which conducts the gas mixture from manifold 21 to appropriate valving which may be solenoid operated as indicated at 24, 25 and 26, for example. A bypass line 5 for the stated mixture of gases from sources 12 and 14 is connected in the manner shown to permit purging of plasma gun 2 through control valve 28. Thus, flow may occur from line 5 directly into gun 2 through valves 28 and 30. Line 144 communicates a powder-gas mixture from feeder 4 to gun 2 when spraying is accomplished.

The structural arrangement shown by FIG. 1, for example, permits purging to remove particles or impurities from the supply system for gun 2 and from the gun itself prior to full operation of the plasma system. By appropriate sequence in actuating control valves 24, 25, 26 and 31, a purging agent in the form of an inert gas from sources 12, 14, or other suitable source may be caused to flow through lines 5, 33, or 35 prior to operation of feeder 4 or gun 2, thereby removing the stated impurities from feeder 4, conduits 5, 142 or 144 and gun 2 before valve 31 is opened to permit powder within container 10 to reach hopper 16 on feeder 4.

Electrical supply means such as generator 6 are provided, together with plasma stream shielding gas source 8, both of which are connected generally as shown. Cooling for plasma

gun 2 is accomplished by a closed or recirculating system using liquid coolant and comprising cooling reservoir unit 7 and pump 9. The rate of powder flowing from feeder 4 may be varied by a handle 18 mounted on control panel 22 and connected to a variable speed transmission forming part of feeder 4. Since feeder 4 may advantageously take the form disclosed in U.S. Pat. No. 2,800,252 issued July 23, 1957, to E. A. Wahl, the details thereof are omitted herefrom except as incorporated by reference to the stated patent.

From the enlarged view of plasma gun 2 shown in FIG. 2, it may be seen that the gun comprises in general a body portion 32 and a handle 34 connected to a cable 36. A dielectric cap 38 is provided to cover and protect knurled adjusting knob 42 which may be used to alter the arcing gap within gun 2 by moving the cathode therein. As also shown in FIG. 2, a clamp 40 may be fastened around body 32 near the forward end thereof to secure a thermocouple 43 in relatively fixed relationship with respect to front face 44. Two adjustable legs 46 are further provided in threaded engagement with bracket or clamp 40 as shown in FIG. 3, for example, to establish a stable reference plane for placement of the plasma stream exit 47 in face 44 at a particular distance from the surface against which the stated stream may be directed. Thus, since the size and temperature of the stream are constant, and the distance of the stream source from the target surface is predetermined and constant by adjustment of legs 46 in cooperative relationship with thermocouple 43, it will be understood that the temperature of the target material will be increased due to the heating effects of the impinging plasma stream at a predictable rate and in a predictable amount for each set of operating conditions of the system disclosed herein. If melting of the target material in the impact area of the plasma stream is undesirable, thermocouple 43 may be used to terminate plasma gun operation automatically when the impact area temperature reaches the point of incipient melting. This point may be detected for each condition of use for the apparatus by determining the amount of temperature rise of the target material at a distance from the impact area coinciding with the location of thermocouple 43, and the rate of such rise resulting from the concentration of heat in the impact area. Thus, for example, if the target material is steel having a melting temperature of 2,000° F., and the temperature of the material contacted by thermocouple 43 is 900° F. when that in the impact area is 1,900° F. or otherwise close to melting temperature, then thermocouple 43 may be electrically connected in circuit with switch 48 to terminate arcing in gun 2 when the thermocouple senses a temperature of 900° F. Such connection may be made in various conventional and well-known ways for using a low-voltage signal to interrupt a circuit.

The internal details of plasma gun 2 are more particularly shown by FIG. 4, wherein it may be seen that the body of the gun is divided generally into two sections comprising an aft body portion 54 and a forward body portion 56. The stated two main body portions 54 and 56 are held together by two threaded elements 58 and 62. Bushing 58 is engaged in close frictional contact within a cylindrical opening formed by the parts which surround it, and is externally threaded at the forward end thereof for engagement with corresponding internal threads on the aft end of insulating bushing 62. Bushing 62 has a flange 63 at the forward end thereof threaded for engagement with corresponding threads 64 formed on the inner surface of ionizing chamber wall 66 at the aft end of body section 56. Threaded engagement between bushings 58 and 62 causes flange 59 on bushing 58 to bear firmly against the aft surface of body section 54 and flange 63 on bushing 62 to bear firmly against the forward surface of body section 54. Thus, it may be seen from FIG. 4 that the operative engagement between bushings 58 and 62 described above causes each of the stated bushings to be centered and securely retained within body section 54. Accordingly, threaded engagement between body portion 56 and bushing 62 by means of threads 64 causes body portion 56 to be securely retained in relatively fixed operative relationship with respect to aft body portion 54. Forward body portion 56 is comprised primarily of ionizing chamber wall 66, cylindrical partition member 68 and outer jacket 76. As shown in FIG. 4, an annular passage 74 is formed between wall 66 and partition 68. Similarly, another annular passage 72 is formed between partition 68 and outer jacket 76. Passage 72 communicates with the atmosphere outside of jacket 76 by means of a plurality of annular slots 82 formed between front face member 44 and outer jacket 76 as shown, for example, in FIG. 3.

The hollow central area of portion 56 forms an ionizing chamber 158 containing a cathode 50 and an anode 60 between which electrical arcing occurs during operation of plasma gun 2. Cathode 50 is mounted in a cathode supporting or holder element 90 is secured thereto by a retainer nut 98. Cathode holder 90 is shown in FIG. 9 isolated from the surrounding structure with which it cooperates in the assembled gun. It may be seen from FIG. 9 that cathode holder 90 is threaded at 93 and 95, with a smooth cylindrical surface 97 between the two threaded portions. The hollow center portion 115 of holder 90 communicates with the exterior surface 97 thereof by means of passage 114 through the upper and lower walls forming surface 97.

In threaded engagement with the interior wall of hollow cathode holder 90 is an orifice member 102, best shown in the isolated views of FIGS. 9–13, inclusive. Orifice member 102 is threaded on its left end as seen, for example, in FIGS. 9 and 10, with a tubular portion on its right. The threaded portion is not completely round, but has flat side surfaces 118 which result in two passages 91 being formed between orifice element 102 and cathode holder 90 when the stated two elements are operatively united as best seen from FIG. 12. Passages 91 thus communicate between cathode coolant inlet chamber 115 and cathode coolant outlet chamber 117 as shown in FIG. 9.

Within the hollow center of orifice element 102 a longitudinal passage 124 communicates with a transverse passage 122 shown, for example, in FIGS. 12 and 13. With elements 102 and 90 in operative engagement, passage 122 in element 102 is aligned with passage 126 in element 90, as shown in FIG. 12, so that a continuous vertical passage through both of the stated elements is formed.

Referring again to FIG. 4, it may be seen that annular passages 110 and 134 are formed between the outer cylindrical surfaces of cathode holder 90 and recessed cylindrical portions on the inner surface of bushing 58. Bushing 58 is centered and supported within plasma gun 2 by a cylindrical mounting ring 88 which fits within a recess of corresponding shape in aft body portion 54. An annular passage 108 is formed between the outer surface of bushing 58 and a cylindrical recess on the inner surface of ring 88. Radial passage 112 through the lower wall of bushing 58 permits communication between annular passages 110 and 108. An inlet coolant line 104 is connected to ring 88 through bushing 87, and communication with chamber 117 in cathode holder 90 by means of passages 108, 112, 110, 114, chamber 115, and passages 91.

The relative position longitudinally between cathode holder 90 and bushing 58 is adjustable by rotation of the stated holder using knurled knob 42. When the desired position is achieved by the stated means, the rotation of holding nut 94 into contact against washer 96 which bears against flange 59 on bushing 58 securely holds elements 58 and 90 in relatively fixed relationship. Plug 92 threadedly engaged in the aft end of holder 90 forms a removable liquidtight seal to close off the aft end of cathode coolant inlet chamber 115.

Due to location of the plane of separation indicated by line 4—4 on FIG. 3, the cross-sectional view of plasma gun 2 shown in FIG. 4 does not show the connection between flexible coolant inlet line 106 and relatively rigid coolant coil 84. However, communication between the stated elements 84 and 106 is maintained by appropriate connection, so that liquid coolant flows from line 106, through coil 84, and into annular passage 74 formed between wall 66 and partition 68. Coil 84 is

open ended and terminates approximately at the location of cutting plane 4—4 shown in FIG. 3, as indicated by dotted line 85 in FIG. 4. By means of the stated relationship of parts, coolant exist from coil 84 into area 75 shown on FIG. 4 which leads into annular passage 74, and thence through aperture 128 to passage 130 communicating with annular passage 132. Passage 132 communicates with combined coolant exit line 140 by means of radial passage 138.

Liquid coolant entering chamber 117 within the hollow forward portion of cathode holder 90 exits from the stated chamber through passage 124 shown, for example, in FIG. 4. Passage 124 within the tubular portion of orifice member 102 connects with annular passage 134 by means of radial passages 122 and 126, best seen from FIG. 12. Passage 134 in turn communicates with annular passage 132 by means of radial passage 136. Exit flow of cathode coolant liquid from chamber 117 thus occurs through passages 124, 122, 126, 134 and 136, whereupon it combines with anode coolant exit flow in passage 132 and leads through passage 138 and combined coolant outlet line 140.

A mixture of inert gases from sources 12 and 14 described above may be fed to plasma gun 2 through inlet line 142 which connects with an annular passage 150 as shown in FIG. 4. Passage 150 connects with a plenum chamber 154 by means of radial passage 152. Plenum chamber 154 is formed by the interrelationship of bushings 58 and 62 with cathode holder 90 as shown in FIG. 4. Exit flow of gases from the plenum chamber occurs through an annular orifice formed by gap 156 between the cooperating surfaces of bushings 62 and cathode holder 90. Exit has flow through orifice 156 fills ionizing chamber 158 from whence it exits through plasma stream exit passage 47 after passing through the continuous arc which occurs between cathode 50 and anode nozzle member 60.

Means are included in the ionizing system disclosed herein for combining metallic powder with the ionizing gas to produce a plasma stream capable of coating a target surface with metal. The stated means include inlet line 144 through which a mixture of metallic powder combined with ionizing gas fed by feeder 4 to plasma gun 2 may be conducted to injection means in the form of powder manifold 86 as shown in FIG. 4. As seen from the isolated views of mainfold 86 shown in FIGS. 14 and 15, the stated manifold comprises a hollowed tube forming a single coil with cathode 50 substantially at the center thereof. Manifold 86 is provided with a plurality of radial inward facing holes 89 through which the combined flow of powdered metal and ionizing gases may be directed generally toward the ionizing arc.

Means are also provided for shielding the plasma stream emitted from exit passage 47 from the deleterious effects of the surrounding atmosphere. The stated shielding means includes inlet line 146 for supplying an appropriate cooling and shielding gas such as CO_2 to chamber 148 formed on the outer jacket 76 as shown by FIG. 4. Chamber 148 communicates directly with annular passage 72 formed between jacket 76 and partition 68 as described above. Gas flowing into annular passage 72 from line 146 exits from the stated passage through annular slots 82 described above. Thus, a cylindrical shaped curtain of gas emitted from slots 82 is symmetrically formed with the plasma stream from exit 47 located substantially at the center thereof.

The arrangement of cable components within handle 34 of plasma gun 2 may be seen from the cross-sectional view of FIG. 8. As indicated thereon, handle 34 may conveniently be formed by two half sections of molded plastic joined together by appropriate means such as screws. In the hollow center of the handle, cathode inlet coolant line 104 and anode coolant inlet line 106, containing power lines 105 and 107, respectively, are arranged generally as shown. In addition to these, lines 140, 142, 144 and 146 described above are contained in handle 34, along with suitable electrical conductors 45 connected to thermocouple 43.

OPERATION

From the description set forth above, it may be seen that the apparatus disclosed herein is adaptable to an extremely wide variety of uses. Operation of the apparatus is essentially the same regardless of the objectives or materials involved in any particular use, and for the sake of illustration will be described in connection with metallic spray coating on a target surface.

Prior to operation of the apparatus for the stated purpose, a source of the metal to be sprayed is connected into the system in the form of magazine 10. This may be accomplished by installing an unopened container of the metal in suitable powdered form as received from the manufacturer directly onto the top cover of hopper 16. The container itself may incorporate threaded fittings of standard type on the top and bottom surfaces thereof for appropriate connection with a valve and a gas pressurizing line, respectively. All joints and mating surfaces throughout hopper 16 and feeder 4 through which contact between the outside atmosphere and the ionizing gas or metallic powder might occur are firmly sealed to prevent such contact. Any of the various familiar and commercially available expedients for sealing conduit joints, valve connections and faying surfaces of flanges or the like may be used to accomplish such sealing in a manner well known to those skilled in the art. Such means may include resilient gaskets or the like as used in garden hoses, for example, or lip seals as shown in U.S. Pat. No. 1,119,968 issued Dec. 8, 1914. As seen from FIG. 18 in the accompanying drawings, the stated seal from U.S. Pat. No. 1,119,968 may be used in the structure of hopper 16 and feeder 4, as shown in FIG. 1 and in U.S. Pat. No. 2,800,252, on lid 57 of the hopper and lid 29 on trough 11. As shown more particularly by FIG. 20, the lid seals may include rubber ring 13 supported by any suitable means on the upper edge of hopper 16 or of trough 11, and adapted to contact a surface of the lid movable relative to each respective item. Means to secure the stated lids may also be provided in the form of an overcenter toggle system as taught by U.S. Pat. No. 1,119,968 and indicated at 15 and 17 in FIGS. 18 and 20 herein. Also, where sealing is desired between hopper 16 and lid 29, resilient ring 19 shown in FIG. 19 and corresponding in construction to ring 13, may be secured to lid 9 and inwardly faced to fit forcibly around a portion 20 of hopper 16 adapted to contact the ring. Many variations differing in detail from the above-described illustrative arrangements may be used to accomplish the same sealing function. Regarding magazine 10, this portion of the powder system may illustratively take the form and function as disclosed in U.S. Pat. No. 2,899,106 issued Aug. 11, 1959, although the system disclosed herein is not limited to the specific details thus taught by the mentioned prior art. Thus, no air or oxygen is allowed to mix with the materials which ultimately will form the plasma stream, and the purity of the powdered metal as received from the manufacturer is preserved and maintained throughout its use in the ionizing system disclosed herein.

Preparation of the system for use also includes connection of suitable gas sources 8, 12, and 14 into the system. As mentioned above, source 8 may comprise a CO_2 bottle. Sources 12 and 14 may, for example, advantageously comprise helium and argon, respectively, for mixing in a ratio of three parts helium and one part argon by weight. Neon and other gases or other mixing ratios may be used without altering the structure or function of the system components disclosed herein, and the materials specified above are merely illustrative.

Cooling of plasma gun 2 during operation thereof may be accomplished by use of water mixed with a suitable agent to lower the freezing point of the coolant, such as ethylene glycol or freon, for example. The stated mixture is supplied to plasma gun 2 under pressure by means of pump 9, and is continuously maintained at a low temperature by means of cooler 7 as shown in FIG. 1. Since novelty of the ionizing system disclosed herein does not depend upon the details of cooler 7 or generator 6, and many different commercially available items are

suitable for use in the system, such details are omitted herefrom.

With the ionizing system connected essentially as shown by FIG. 1, operation of plasma gun 2 may be commenced by actuation of appropriate electrical means such as switch 48 shown, for example, in FIG. 4. This may cause immediate circulation of coolant through gun 2, as well as flow of CO_2 from source 8 through slots 82 as set forth above. By appropriate conventional time delay mechanisms mounted on each of the solenoid operated valves 24, 25, 26, 28 and feeder 4 in a manner known to the prior art, actuation of switch 48 may cause the stated items to operate in a particular predetermined sequence. For example, valves 24, 25 and 28 may advantageously be timed to open before hopper 16 is pressurized by valve 26 or before feeder 4 begins to feed metallic powder to gun 2. Thus, during flow of coolant and CO_2 through gun 2, a mixture of inert gases from sources 12 and 14 may blow through gun 2 at low pressure before power is supplied by generator 6 to cause arcing between cathode 50 and anode 60. The initial flow of inert gases through the ionizing system achieved in the stated manner serves to purge the system of foreign material including atmosphere and oxygen, besides permitting the ionizing arc to be struck in an oxygen-free environment. Moreover, an arc is more quickly and easily established during low rate of gas flow through the ionizing chamber, whereas in devices in the prior art the arc is often extinguished by high initial gas flow rates. After a sufficient period of time to allow complete purging such as 5 or 6 seconds, during which period the arc will have stabilized, the time delay mechanisms on valves 26 and 31 may operate the valves to cause pressure from inert gas sources 12 and 14 to be applied to container 10, hopper 16 and feeder 4. Coincident with the application of such pressure, actuation of feeder 4 may cause metallic powder to be fed to gun 2 at a rate determined by the position of lever 18 on control panel 22 acting upon the variable speed transmission incorporated in the feeder.

During operation of pump 9, liquid coolant such as described above is supplied under pressure to plasma gun 2 through two inlet lines 104 and 106, and returned from the gun through combined coolant exit line 140. Circulation of the coolant occurs through gun 2 in accordance with the description set forth above. Additional cooling effects are obtained from the use of CO_2 as the shielding gas due to its low temperature, since heat from coolant within passage 74 is partially transmitted through partition 68 to the pas in passage 72.

Upon discontinuing operation of plasma gun 2, such as may be effected by release of switch 48, time delay mechanisms incorporated on system components as described above may be set to cause automatic purging of the gun. Thus, for example, the flow of metallic powder from feeder 4 may be terminated by closure of valve 31 and stopping the mechanical drive to trough 11 before valves 26 and 28 are closed, resulting in a flow of inert gases from sources 12 and 14 for a period of time, such as 5 or 6 seconds, sufficient to purge the plasma gun and connected lines completely. During the purging period, electrical powder connections to cathode 50 and anode 60 may be interrupted to terminate arcing. By use of the stated procedure, arcing will not occur in gun 2 in an oxidizing atmosphere at the time operation of the gun is discontinued.

In addition to the features discussed above, the novel ionizing system disclosed herein includes means for controlling the temperature of the plasma. The stated means includes a control valve 30 of variable position which may be manually adjusted and thereafter automatically operated as by sensing downstream pressure, for example, to maintain a substantially constant preset flow rate through valve 30 by restricting or otherwise varying the area of the valve opening through which the ionizing gas flows en route to plasma gun 2. Valve 30 may take any of several forms known to the prior art, and no claim of novelty is asserted herein with respect to the details of valve 30 as a subcombination.

Valve 30 functions to control the temperature of plasma emitted by gun 2 by reason of the natural phenomena associated with the ionizing process itself. These phenomena include the fact that the temperature of the ionizing arc increases when the pressure within the ionizing chamber is increased. Moreover, the temperature of the plasma stream varies in direct proportion to the rate of flow of ionizing gas through the ionizing chamber in gun 2. By increasing the flow rate of ionizing gas through the arcing chamber in gun 2, and keeping the exit nozzle area in the stated chamber constant, an increase in temperature of the plasma stream will occur due both to the increased amount of gas being ionized and to the characteristics of the ionizing arc in a higher pressure environment. Thus, valve 30 provides a stable plasma stream temperature by maintaining constant gas flow rate into gun 2.

The apparatus and procedures described above provide several notable advantages and benefits not achieved by devices known to the prior art. Among these are greater stability of operation, longer electrode life, greater purity of the metallic coating on the target material, and increased safety of the operator during use of the ionizing system disclosed herein. In addition to these benefits, the apparatus disclosed herein has been found to provide substantial improvement over the prior art systems in spray coating materials, the properties of which render such materials inherently difficult to entrain in an ionized gas stream in such other systems due to the polarity of the plasma stream. Improved performance of the instant system results primarily from the use of an annular manifold within gun 2 for combining metallic powder with the gas used in producing the plasma stream. By this means, the powder is entrained in the gas before it is ionized and the mixture is then passed through the arc which causes the ionizing. The manifold accomplished this function without causing clogging at the outlet nozzle and the gun could be operated continuously as long as powder and gas are supplied thereto. Improved electrode life in the apparatus described above results partially from the improved cooling of the cathode and the anode by the means described in detail above. Experience has shown that ablation of electrodes during arcing therebetween occurs at a higher rate when electrode temperature is increased, and effective cooling of the electrodes is accompanied by a substantial decrease in the deleterious effects of ablation. In addition to the stated cooling effects, electrode life in the novel apparatus disclosed herein is further prolonged by use of the purging system discussed above. Thus, arcing between the electrodes in an environment entirely free of oxygen necessarily prevents oxidation of the electrode material. Moreover, it is an essential feature of the inventive concept that the novel ionizing system disclosed herein includes means for insuring that the purity of the metallic powder as received in shipping containers from the manufacturer is carefully and continuously maintained from the time containers are initially received until the metal in plasma form impinges upon a surface. Thus, as a result of the structures and methods discussed in detail above, no mixing of air with such powder or in fact any contact between atmosphere and such powder is allowed to occur at any time during its use in the system. The coating produced by the plasma gun disclosed herein is of uniform density, adheres permanently to the target surface and is free of impurities. No charred particles or lumpy masses such as produced by oxidizing of sprayed material occurs in the stated coating.

Finally, great versatility of the novel system disclosed herein in spraying various materials in powdered form results from incorporation of the plasma temperature control means described above. Thus, for example, tungsten carbide may be sprayed using this invention without resulting in oxidation, combustion or other deleterious effects on the coating by adjusting the system parameters to provide a temperature in the ionizing chamber and plasma stream on the order of 5,000° F. The coating of tungsten carbide which results on the target material is of improved purity and adheres thereto with exceptional tenacity such as cannot be achieved by spray coating

devices in the prior art. Conventional ionizing devices provide arc and plasma system temperatures far in excess of 5,000° F., hence are incapable of effectively spraying tungsten carbide, since the stated material will dissociate at higher temperatures. Conversely, where extremely high ionizing temperatures are necessary, such as in spraying materials having high melting points, the apparatus disclosed herein may be adjusted to provide temperatures on the order of 40,000° F. with adequate cooling during safe, sustained operation at such elevated temperatures.

I claim:

1. In a plasma gun for ionizing a stream of gas, said gun including a double-walled chamber containing an elongate cathode and an annular anode for striking an ionizing arc upon the application of electrical power thereto;

cooling means for cooling said anode and said chamber,

said cooling means including a source of cooling fluid at relatively low temperature and a supply line connecting said source and said gun for flowing said fluid from said source to said gun,

said cooling means further including coil means between the said walls of said chamber for conducting said fluid from the inlet connection of said line and said gun directly to the area between the walls of said double-walled chamber in closest proximity to said anode,

said cooling means further including a return line for returning said fluid from said gun to said source, and heat exchange means connected between said source of cooling fluid and said gun for lowering the temperature of said cooling fluid.

2. The apparatus as set forth in claim 1 above, wherein:

said coil means comprises a hollow tubular coil and

said cooling means further includes passage means between said walls for flowing said cooling fluid over said hollow tubular coil and between said walls.

3. In a plasma gun for ionizing a stream of gas, said gun including an elongate cathode and an annular anode for striking an ionizing arc upon the application of electrical power thereto;

mounting means for adjustably holding said cathode with one end thereof in spaced relationship with respect to said anode,

said mounting means being contained within a double-walled chamber having two generally concentric and spaced-apart walls forming a portion of said gun,

said mounting means including a closed chamber coaxially aligned with said cathode and said double-walled chamber, said closed chamber surrounding a substantial portion of said cathode,

first cooling means for flowing a cooling agent through said closed chamber in contact with said portion of said cathode to cool the same,

second cooling means for cooling said anode and said double-walled chamber,

a source of cooling fluid at relatively low temperature, and

a supply line connecting said source to said gun for flowing said fluid from said source to said gun,

said second cooling means further including coil conduit means situated in said space between said double walls for conducting said fluid from the inlet connection of said line and said gun directly to an area between walls of said double-walled chamber, said area being situated in close proximity to said anode.

4. In an ionizing system for a plasma gun adapted to spray coat powdered material on a target surface:

hopper means for storage of said material,

feed means adapted to receive said material from said hopper means and feed the same to said gun at a predetermined rate,

means rendering said hopper means and said feed means airtight to prevent contact of air with said material while contained in said system so that said material is preserved in the same state of purity when fed into said gun as when placed in said hopper,

a source of gas,

first conduit means connecting said source of gas to said hopper means

second conduit means connecting said source of gas to said plasma gun through said feed means, and

valve means for selectively flowing gas from said source through said second conduit means, said feed means and said gun in an amount sufficient to purge all gases and particles from within said conduit means, said feed means and said plasma gun.

5. In an ionizing system:

a plasma gun,

feeder means for feeding powdered material to said gun,

conduit means connecting to said feeder means with said gun,

purge means connected to said feeder means for flowing a purging agent through said feeder means, said conduit means, and said gun in amount sufficient to purge all gases and particles from therewithin other than said agent,

a source of said powdered material operatively communicating with said feeder means,

said purge means comprising a source of gas,

first conduit means connecting said source of gas with said source of powdered material, and

bypass means selectively operable to bypass said source of powdered material by connecting and disconnecting said source of gas with said feeder means for flowing said gas through said feeder means, said gun, and said conduit means connecting said feeder means with said gun.

6. The structure set forth in claim 5 above, further including:

valve means between said source of powdered material and said feeder means for selectively permitting and preventing said operative communication of said source of powdered material with said feeder means.

7. Apparatus for spray coating powdered materials on a target surface by mixing said materials with a stream of gas and ionizing a portion of said mixture, said apparatus comprising:

a plasma gun,

chamber means in said gun containing electrode means for striking a continuous ionizing arc through which said mixture flows,

perforated manifold means within said chamber means including a tubular manifold at least partially encircling the area of said arc and having a plurality of radially inwardly directed holes in said manifold for conducting said materials to said area,

feeder means for feeding powdered material to said manifold,

conduit means connecting said feeder means with said manifold,

purge means connected to said feeder means for flowing a purging agent through said feeder means, said conduit means, and said manifold in an amount sufficient to purge all gases and particles from therewithin other than said agent,

a source of said powdered material operatively communicating with said feeder means,

said purge means comprising a source of gas,

first conduit means connecting said source of gas with said source of powdered material,

bypass valve means selectively operable to bypass said source of powdered material by connecting or disconnecting said source of gas with said feeder means for flowing said gas through said feeder means, said manifold, and said conduit means connecting said feeder means with said manifold

second conduit means connecting said source of gas to said gun for ionization of by said arc, and

control valve means in said second conduit means for automatically controlling a flow rate of said gas through said second conduit means to maintain a constant predetermined rate of flow.

8. Apparatus adapted to spray coat powdered materials on a target surface by mixing said materials with a stream of gas and ionizing a portion of said mixture, comprising:

a plasma gun having a chamber therein containing electrode means for striking a continuous ionizing arc through which said mixture flows,

perforated manifold means including a tubular manifold at least partially encircling the area of said arc and having a plurality of radially inwardly directed holes in said manifold for conducting said mixture to said area,

feeder means connected to said manifold means for feeding powdered materials to said gun,

said feeder means including means for automatically controlling said feed of powdered materials at a constant feed rate,

a source of gas connected to said feeder means and to said gun for flowing said gas through said feeder means and said gun,

said chamber having double spaced-apart walls,

said electrode means comprising an elongated cathode and an annular anode for striking said ionizing arc upon the application of electrical power thereto,

cooling means for cooling said anode and said chamber, said cooling means including a source of cooling fluid at relatively low temperature and a supply line connecting said source and said gun for flowing said fluid from said source to said gun,

said cooling means further including coil means between said double walls of said chamber for conducting said fluid from the inlet connection of said supply line and said gun directly to the area between the walls of said double-walled chamber in closest proximity to said anode,

and said cooling means further including a return line for returning said fluid from said gun to said cooling fluid source, and heat exchange means connected between said source of cooling fluid and said gun for lowering the temperature of said cooling fluid.

9. The structure set forth in claim 8 above, including in addition thereto:

control valve means connected between said source of gas and said gun for automatically controlling a flow rate of said gas to maintain a constant predetermined rate of flow of said gas to said gun.

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