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United States Patent

Perugini et al.

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[45] **Aug. 15, 1972**

[54] PLASMA-JET GENERATOR FOR VERSATILE APPLICATIONS

[72] Inventors: **Giancarlo Perugini,** 11, Via G. Leopardi, Merano (Bolzano); **Giorgio Marcato,** 33, Via Druso, Bolzano; **Luigi Belotti; Carmelo Caccamo,** both of 9/A Via Goethe, Merano (Bolzano), all of Italy

[22] Filed: **Aug. 25, 1970**

[21] Appl. No.: **66,852**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 709,677, March 1, 1968, abandoned.

[52] **U.S. Cl.** .....**313/231,** 219/74, 219/75, 219/121 P, 313/23

[51] **Int. Cl.**.....**H01d 17/26**

[58] **Field of Search** ..313/23, 231; 219/74, 75, 121 P

[56] **References Cited**

UNITED STATES PATENTS

3,390,292 6/1968 Perugini 313/23

Primary Examiner—John Kominski

Attorney—Curt M. Avery, Arthur E. Wilfond, Herbert L. Lerner and Daniel J. Tick

[57] **ABSTRACT**

Improvement of the plasma-jet generator described in U.S. Pat. No. 3,390,292 to Perugini, by improving the water cooled anodic surface, and an anode adapter using an interchangeable set of electrodes forming and stabilizing the plasma-jets. This provided higher cooling efficiency and higher operative resistance of the anode and wider suitability of the generator in forming plasma-jets of higher power and wider utility.

19 Claims, 23 Drawing Figures

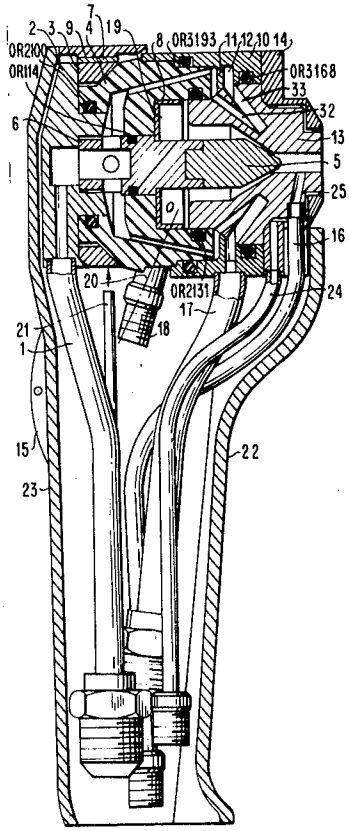


FIG. 1

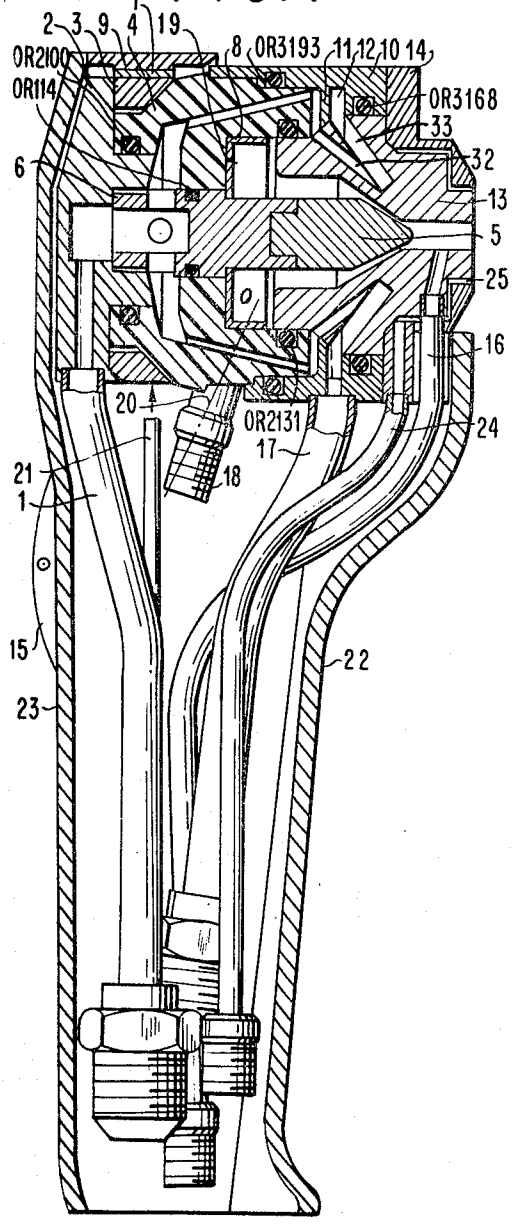


FIG. 5

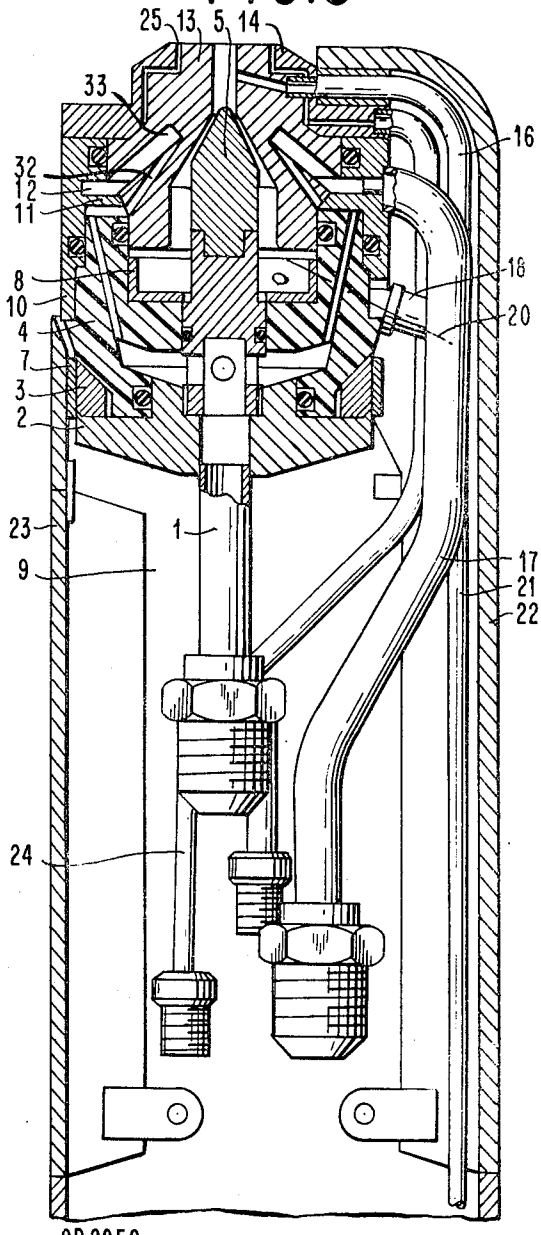


FIG. 9A

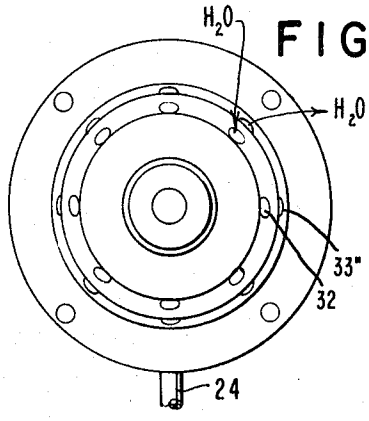


FIG. 9

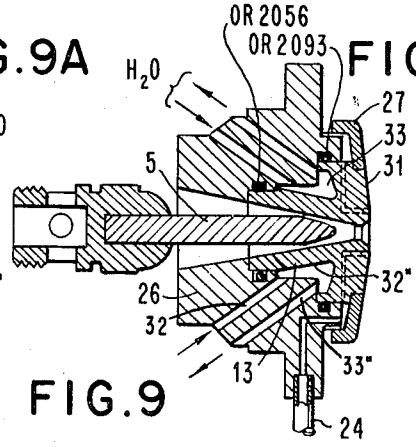


FIG. 9B

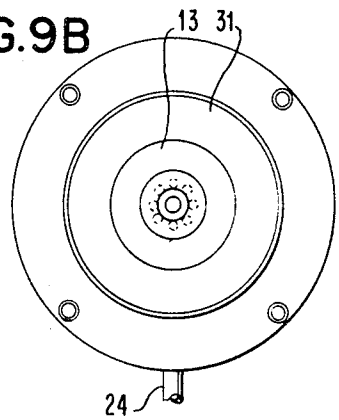
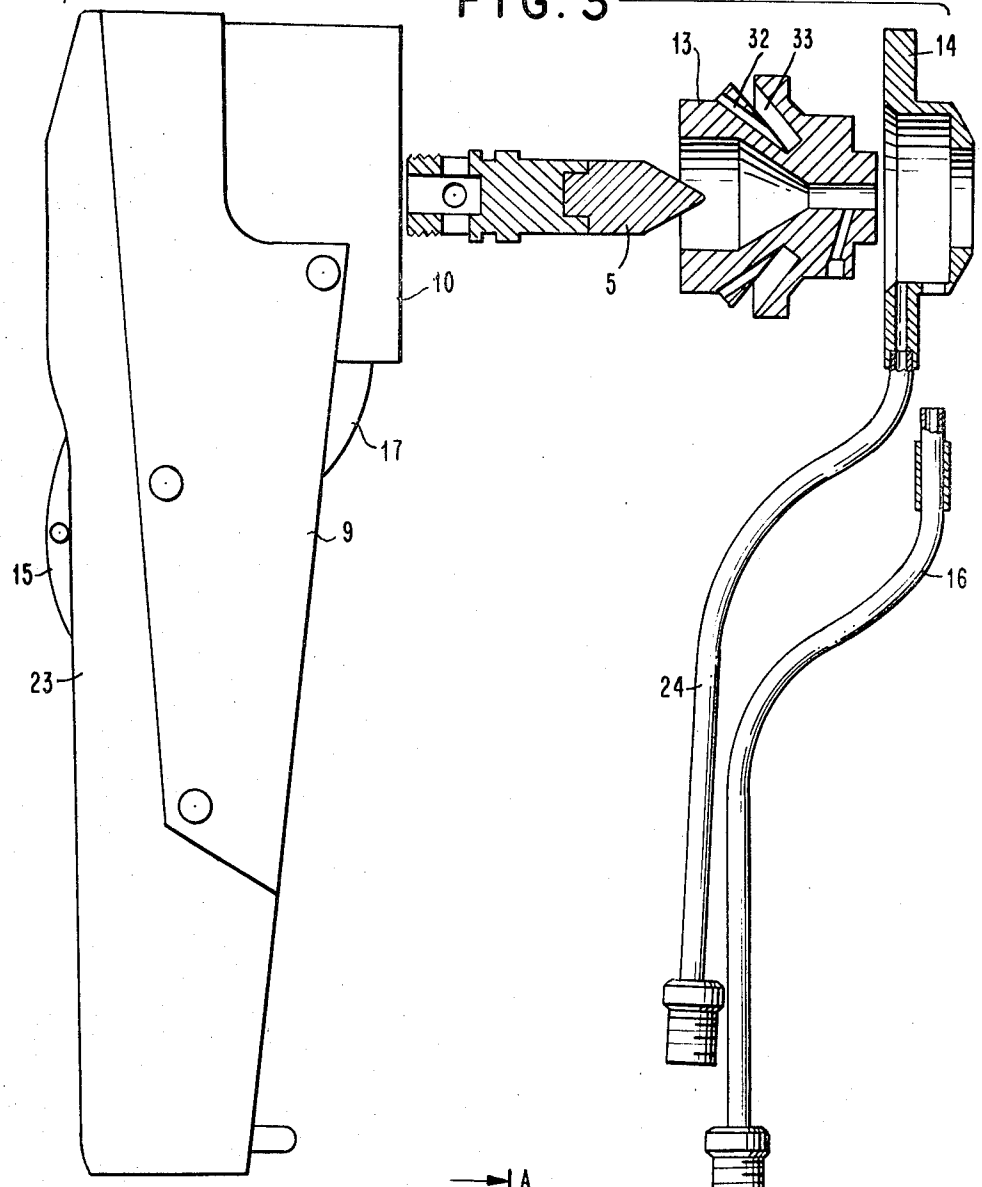


FIG. 3



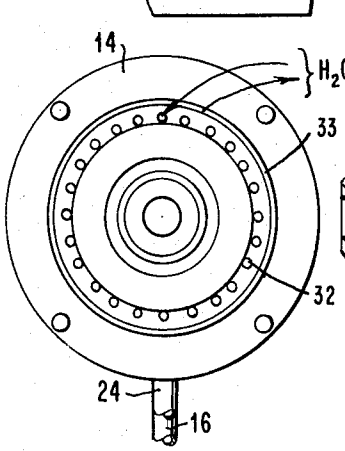


FIG. 2B

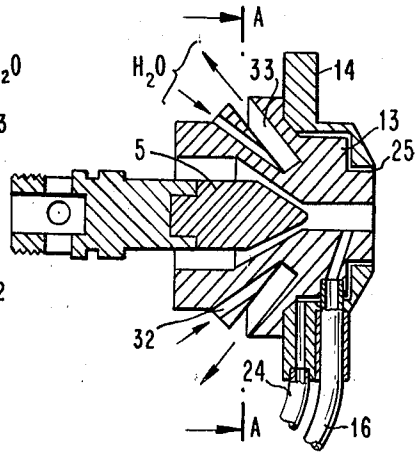


FIG. 2

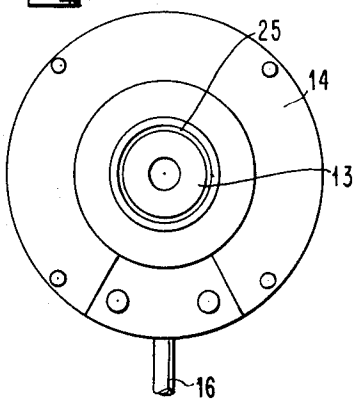


FIG. 2C

FIG. 10

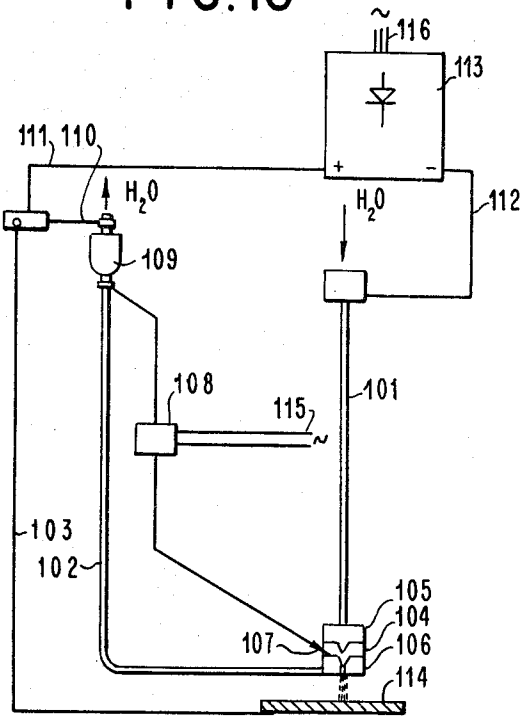
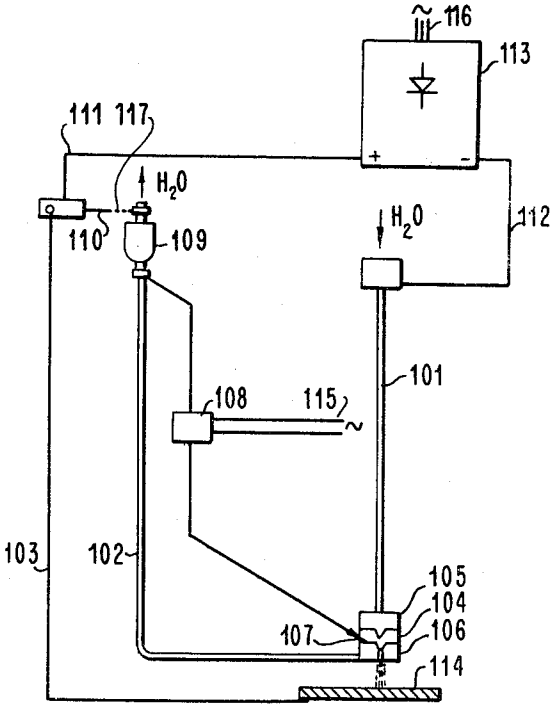


FIG. 11



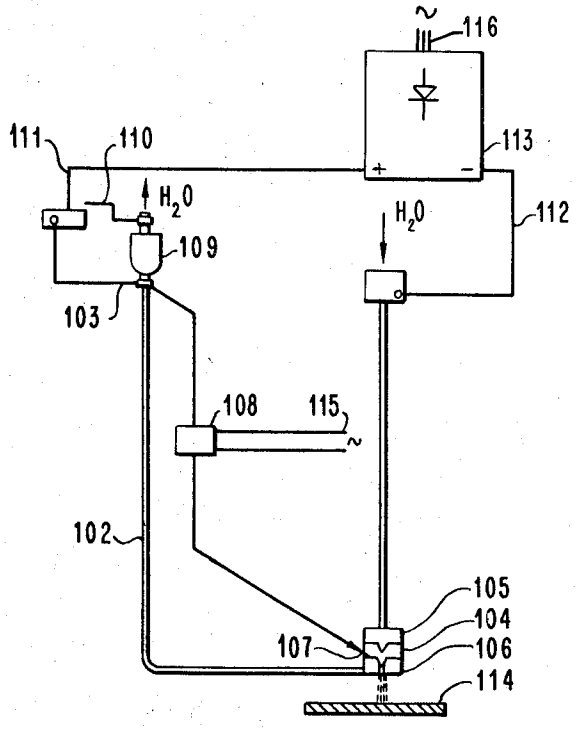
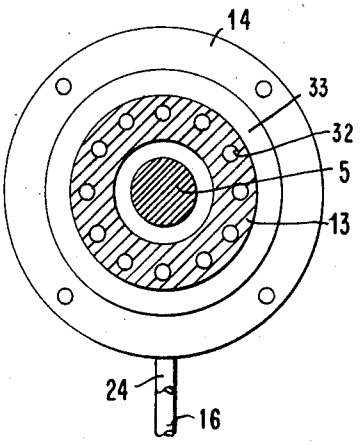


FIG. 12

FIG. 2A



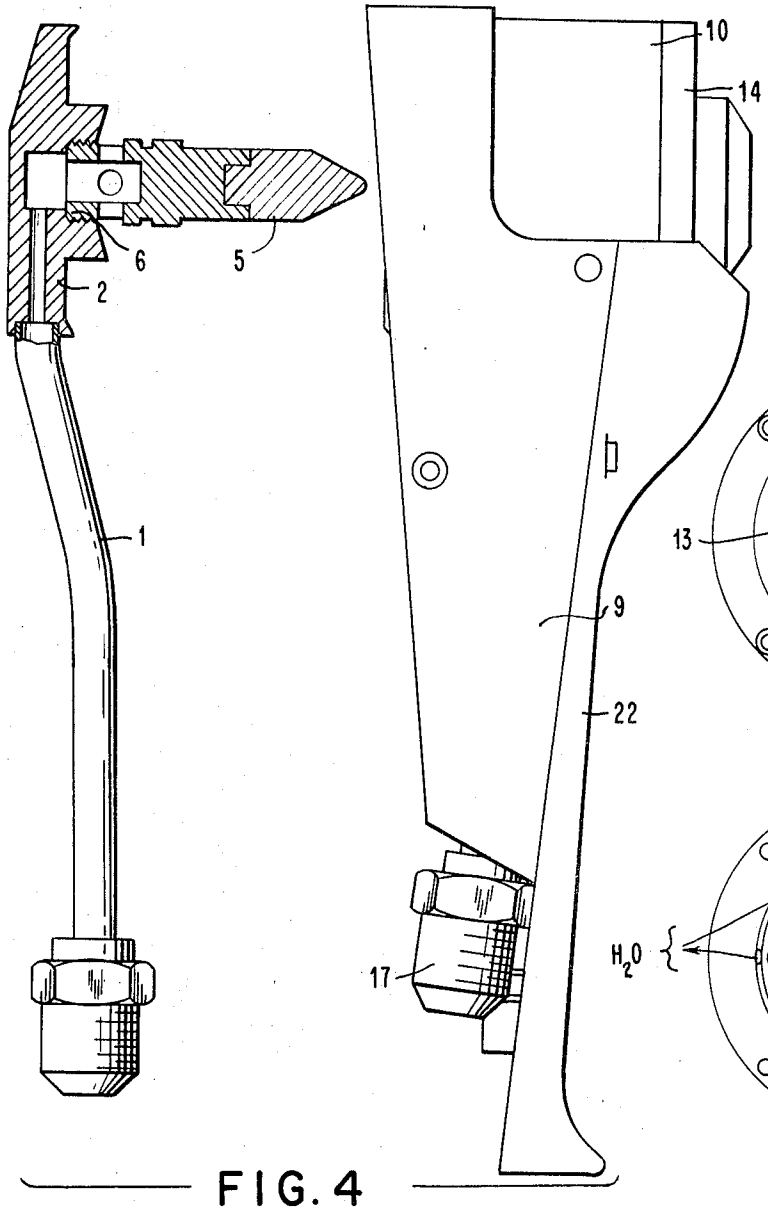


FIG. 4

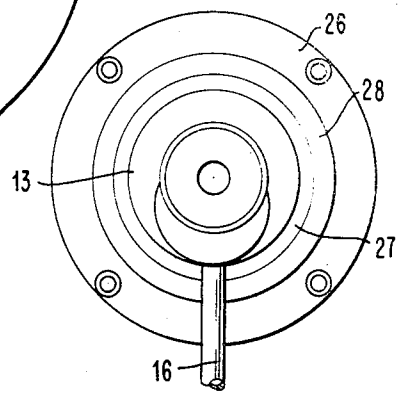


FIG. 7C

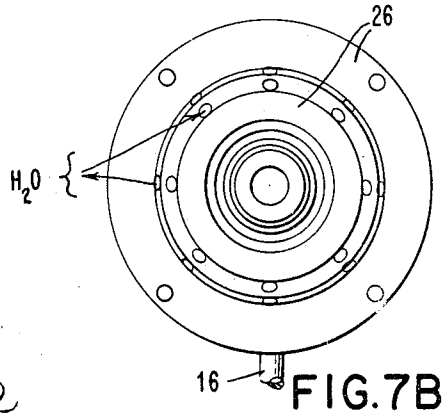


FIG. 7B

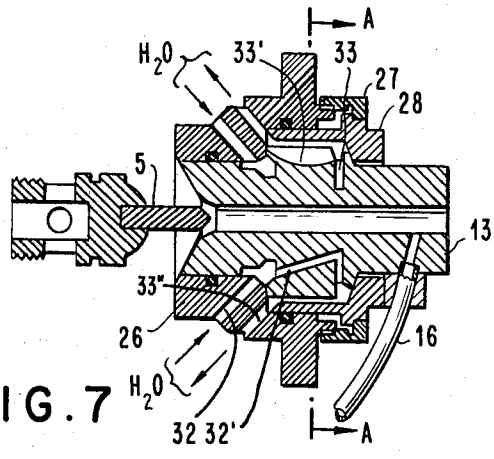


FIG. 7

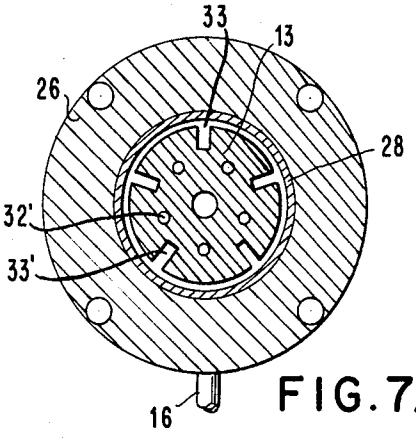


FIG. 7A

FIG.6

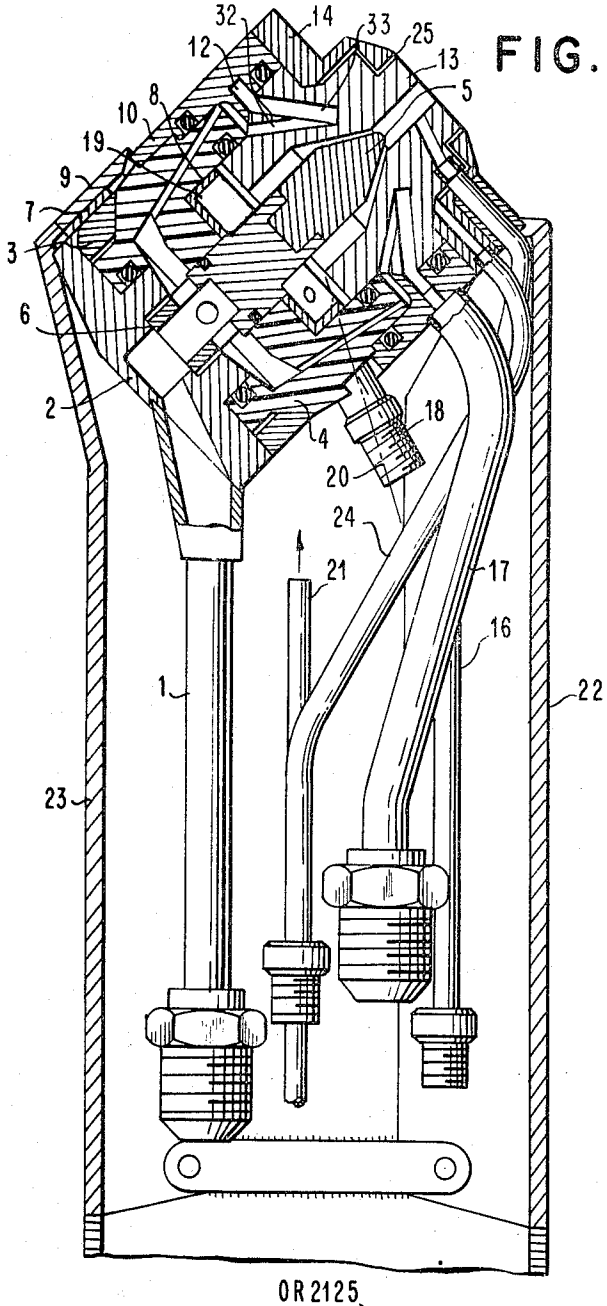


FIG.8B

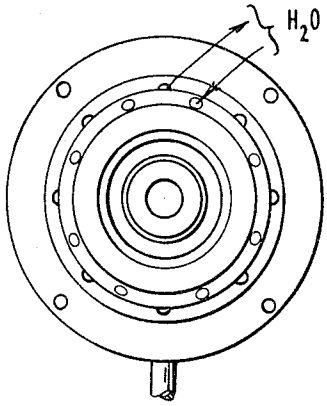
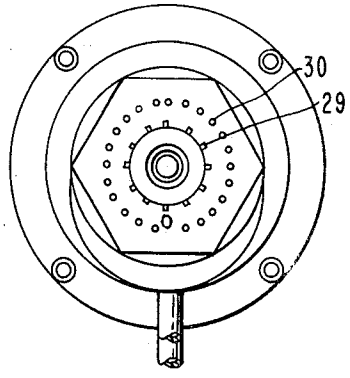


FIG.8C



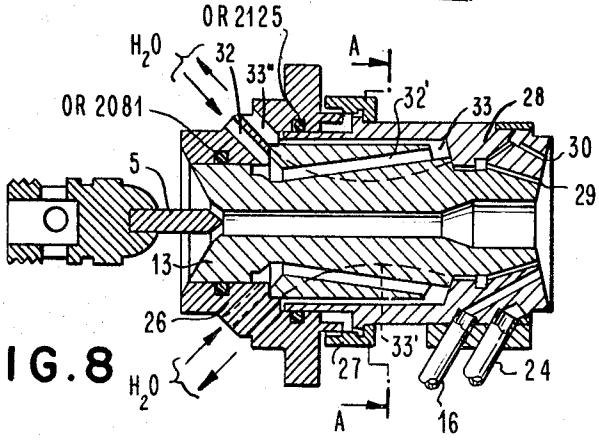
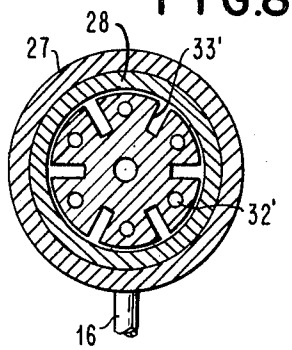


FIG.8

FIG.8A



PLASMA-JET GENERATOR FOR VERSATILE APPLICATIONS

This invention is a continuation-in-part of application Ser. No. 709,677, filed Mar. 1, 1968 now abandoned and relates to an improved plasma-jet generator having an anode of high resistance to heat and being able to operate in a range of power densities from 0.5 up to 4.5 kW/mn^2 and ratios of power/arc gas flow, exceeding 10 and up to 30 kW/m^3/h.

Reference is made to the art of generating plasma-jets and of employing the same in several technical applications. The present invention relates to improvements of the plasma-jet generator described in U.S. Pat. No. 3,390,292 to Perugini.

In a plasma-jet generator, comprising a cathode, an interelectrode electro-insulating element and an anode (said cathode and anode being coaxial electrodes), U.S. Pat. No. 3,390,292 to Perugini, discloses a cooling system which comprises means for injecting a stream of water against the rear of the cathode, multiradial directrixes determined by the rear configuration of the cathode for passage of water to circumferential water passages in the electro-insulating element for conveying the cooling water through said element to the anode, said passage being coaxial to the electrodes and equidirectional to the plasma jet, and means for passing cooling water around the anode to cool the same, said anode has an axial nozzle which presents a series of parallel, cylindrical and truncated-conical shapes obtained on an integral copper body, multiradial directrixes in a first portion of said anode through which the cooling water flows with a centripetal movement and then along a main portion, with a water passage which is circumferential coaxially, and equidirectional with the plasma jet, and finally a ring of holes arranged radially and obliquely on the external annular wall of the anode, an annular diaphragm supporting the anode and a circular discharge collecting zone so that the water entering the anode and the discharge collecting zone are adjacent each other though separated from each other by said annular diaphragm.

In the known art utilization of plasma-jets of non-transferred arc type for spray procedures for producing protective coatings by a gas shielded short electric circuiting arcing system, the parameters, such as current density, power density, and ratio of power/arc gas flow, appear to be contained below the following values: 10 Amp/mm^2; 0.5 kW/mm^2; and 10 kW/m^3/h, respectively, because if higher power is utilized, the arc gas flow being unchanged, a damage can occur in the electrodes, while if the arc gas flow is also made higher, the arc is modified to a gas constricted long electric circuiting arcing inside the anodic hole, and results in an excessive flow rate of the plasma-jet issuing. Under these conditions, although the devices show a satisfactory performance, the flow of flame in contact with the nozzle walls does not possess a sufficiently high temperature for the fusion of the material, particularly powdered material, passing through said zones in the pronouncedly short retention times. This is particularly the case where the arc gas flow is also made higher.

It is an object of the present invention to provide an anode of improved heat resistance in the plasma-generator of Perugini and to make higher the plasma power obtainable by the generator. Other objects are to make the device more handy and widen the practical applications of the device in the several specific fields of plasma technology.

It has now been found that the anode resistance can be increased and the power of the plasma-jet made higher if the system, according to which the water flows entering to the anode, is modified so that the water can strike the anode surface more vigorously.

The invention consists of a newly cooled anode, and more particularly of a new anode design by which the position of the ring of holes and of the groove in the anode is inverted, with reference to the Perugini plasma generator, so that the water coming from the interelectrodic electro-insulating element is entering equidirectionally to the plasma-jet multiradially and centripetally, through a ring of holes which is placed in the inner part of the anode and coaxially to the plasma jet. In this way, the water leaves the anode through a groove placed in the outer part of the anode according to traverse position to the axis of the same anode, so that the water flows multiradially centrifugally and in opposite direction to the plasma jet towards a circular discharge collecting sump. Another feature of the invention concerns the substitution of the anode with an insert of at least two pieces, the first of which is an anode adapter and the second of which is the true anode. At least the adapter, having in its center a cylindrical or frusto-conical hole, is provided with a double frusto-conical ring of holes, the central hole and the rings of holes being coaxial each other and to the plasma generator. The water, coming from the interelectrodic electro-insulating element, is forced inside the holes of the inner frusto-conical (truncated-conical) ring, towards the anode, and is discharged from the anode through the holes of the outer truncated-conical ring of the anode adapter. The anode connected to the anode adapter may or may not have holes and grooves longitudinally placed in form of ring, inside the body of the anode and coaxially to the nozzle of the same.

The special design of the anode adapter and/or of the anode assures a surprising better anodic cooling effect by a better striking action of the water against the surface of the anode.

By means of the anode adapter, different types of anodic inserts can be coupled with the plasma generator which so reaches larger possibilities in several specific plasma-jet applications.

The invention will be described in greater detail with reference to the drawing, in which:

FIG. 1 shows in sectional view a plasma generator, in gun form according to our invention, provided of cathode and anode (interchangeable insert) for plasma arc of "non-transferred" type and for spray operations. The insert is to be employed with the use of noble gas (or noble gas mixtures) for blowing and stabilizing the plasma-jet;

FIG. 2 shows a cross section of an interchangeable insert of which the gun plasma generator of FIG. 1, is provided;

FIGS. 2A, 2B and 2C, show respectively, a cross section along line AA of FIG. 2 and left and right views of FIG. 2;

FIGS. 3 and 4 show the extractability of the cathode from the front and rear respectively;

FIGS. 5 and 6 show a sectional view of the plasma generator in head shape at 90° and at 45° respectively;

FIGS. 7, 7A, 7B and 7C show, respectively, a cross section of another interchangeable insert, a cross section along line AA and left and right end views thereof; the insert comprises cathode, anode, and anodic adapter for plasma arc of "non-transferred" type and for "spray" operations. The insert is to be employed with the use of nitrogen (or hydrogen or mixture thereof), for blowing and stabilizing the plasma-jet;

FIGS. 8, 8A, 8B and 8C show, respectively, a cross section of still another interchangeable insert, a cross section along line AA and the left and right end views thereof; the insert comprises cathode, anode, anodic adapter for plasma arc of "non-transferred" type and for spraying plastic materials (named "Plastospray" operations). The insert is to be employed with the use of nitrogen (or hydrogen or nitrogen/hydrogen mixtures) for blowing and stabilizing the plasma-jet;

FIGS. 9, 9A and 9B show, respectively, a cross section of another interchangeable insert and the left and right end views thereof; the insert comprises cathode, anode and anodic adapter for plasma arc of "-prevailingly transferred" type and for "rapid cut" operations. The insert is to be employed with the use of argon gas or argon/nitrogen or argon/hydrogen mixtures;

FIG. 10 shows a diagram for arc plasma of the "-prevailingly transferred" type;

FIG. 11 shows a diagram for arc plasma of the "-totally transferred" type; and

FIG. 12 shows a diagram for "non-transferred" arc plasma.

In greater detail the longitudinal section of the plasma generator in the pistol type version of FIG. 1 is provided with the insert shows separately in FIG. 2; FIG. 2A shows a section of the device through section AA of FIG. 2; FIGS. 2B and 2C show the left and right end views, respectively, of FIG. 2.

The upper part of cathode tube 1 of negative polarity, which supplies continuous electrical current and cooling water, is welded onto an obturator 2 of the cathode compartment. The obturator, which seals the cathode compartment, is fastened, preferably by screws, to the metal conical seat 3, which in turn is connected by screws and/or threading to the interelectrodic electro-insulating element 4, constituting an interchangeable insert. Thus the obturator also acts as the cathode support. A portion of tube 1 protrudes along the axis of obturator 2 so that it injects water into the groove of cathode 5, which is fixed to the inner wall of obturator 2 by means of screw threads. The cathode can be advanced up to 3 mm by simply inserting additional small washers in the interface zone 6 until the initial clearance at 7 is eliminated, in order to compensate for consumption of the tungsten tip during its operating life. This increases the working life of the cathode and accordingly reduces the depreciation of the cathode. The cooled anode 13 has its maximum cylindrical dimension in the central portion. This dimension forms the hydraulic seal with the "O" ring, OR 2131. Thus the cathode can be extracted from either the front or the rear of the interelectrodic electro-insulating body. This greatly facilitates the inspection and the maintenance of the cathode. FIGS. 3 and 4 show its double extractability. All figures use the same numerals for the same feature. Returning to FIG. 1, the other parts of the plasma generator are: The anti-radiation template 8 of ceramic material which attenuates the surface temperature on the walls of the arc gas chamber thus avoiding alteration of the organic electro-insulating material 4; the anode support 10 comprising the annular deflector 11 and the water discharge collecting sump 12, the specially cooled anode 13; the anode tightening ring 14 which distributes the auxiliary gas (protective and cooling gas) delivered through tube 24 and expelled through the ring of distributing holes 25; the powder injection tube 16; water passages 32 and 33 for cooling the anode; anode tube 17 for the cooling water discharge and for the return of the electrical current; tube 18 for the tangential injection of the gas into the arc chamber; gas vortex chamber 19; the small auxiliary electrode 20 for striking the arc by sparking on the anode with the aid of an auxiliary electrical circuit. "O" rings OR 2100, OR 114, OR 3193 and OR 3168 create efficient seals at various locations in the device.

The external casing of the generator consists of a central part 9 fastened to the generator body by a screw on each side, at the front, together with a ring at the rear tightening the generator body by means of an interposed electro-insulating socket 7 having the function of preventing the electrical contact with the cathodic compartment. Fastened to the central casing 9 are a front cup 22 and a rear cup 23 provided with tongue 15 suitable for mechanically attaching the plasma generator to a holder.

There is also the small tube 21 which is for injecting compressed air for cooling the electro-insulating interelectrodic element. The air jet, in fact, strikes the bottom of the electro-insulating interelectrodic element, embraces the sides of its body, and then goes upwards and passes out through the slit existing between the upper part of the central casing 9 and the upper part of the anodic support 10. In this way, the electro-insulating interelectrodic element, which is the part most sensitive to the actions of overheating, is cooled by the combined action of the water flow inside the element and of the external flow of compressed air circulating between the device casing and the external surface of the interelectrodic electro-insulating element.

The plasma-jet generator may be constructed not only in the pistal shape version, but also in head shape at 90° or head shape at 45°, as illustrated in FIGS. 5 and 6, respectively. With these shapes the functional structure of the generator does not vary although the exterior configuration especially in the lower rear part is modified. For particular applications inside narrow and deep parts, these versions are much more practical and handy above all for mechanized operations. Further discussion of these latter versions is superfluous since they have functionally been described by the description for the pistol version which carries the same numbers.

The generator is operated in any of its many operating embodiments as follows: After having connected the generator to a source of continuous current, by copper plaits arranged inside suitably flexible rubber tubes with water circulation, and having sent water into the circuit and selected gas for the arc chamber feeding, the electrodes are put under electrical tension. A

spark between the small auxiliary electrode and the anode is then ignited to ignite the arc with a plasma-jet coming out from the nozzle. Upon ignition of the plasma, the voltage between the idling electrodes undergoes a sudden diminution, whereas the current increases correspondingly. The opening voltage for argon is about 70 Volts; for mixtures of argon/nitrogen and argon/hydrogen, it is about 140 Volts, and for hydrogen or nitrogen, it is about 280 Volts.

For the sake of clarity, several terms used in the specification will be here defined.

a. "Spray" procedure is the process by which a metallic material (from low-melting to refractory), a ceramic material or a mixture thereof, is projected in molten state onto a metallic or non-metallic surface to produce on said surface a protective coating which adheres to the surface with a bond of prevailingly mechanical nature. The material as a powder is injected into a flame, i.e. "non-transferred" arc plasma-jet, within which it undergoes the dynamic melting.

b. "Saldospray" is the analogous process relating to the deposition of a metallic coating material on a metallic base material, wherein the interfacial zone is characterized by pronounced or predominating metallurgical bonds which are concreted in only one stage, i.e. concomitantly with projecting the coating matter which is deposited in molten state and is practically pore free. In this process, the mechanical bonds are of secondary importance and in some cases they are negligible with respect to the predominating metallurgical bond. The projection, the fusion of the coating matter and the metallurgical bond of the latter on the metal base surface, are dynamically performed by utilizing the energy of the "-prevailingly transferred" arc plasma.

c. "Plastospray" procedure is a process similar to the "spray" process but where the coating matter is of organic nature and more precisely is a thermoplastic or thermosetting polymer which when injected in the powder state within the flame-jet (i.e. "non-transferred" arc plasma-jet) undergoes in the jet a dynamic fusion and then deposits as a film coating on the surface of a metallic or non-metallic body.

d. "Melt-cut" procedure is the process by which non-electro-conducting materials are cut by localized melting with the aid of the energy of the "non-transferred" arc plasma jet.

e. "Rapid-cut" procedure is the process by which electro-conducting materials, especially more or less thick metal sheets or metal parts in general, are cut or perforated at high rates by localized melting utilizing the concentrated energy of the "-transferred" arc plasma which may have the function of pilot arc, so as to result in either the case of "prevailingly transferred" arc or of "totally transferred" arc.

In the "non-transferred" arc plasma, there is only one electrical circuit wherein the entire current intensity is transmitted from the cathode to the nozzle-shaped anode, through the plasma coming out from the anode nozzle. The workpiece, which is subjected to the plasma jet, doe s not form part of the electrical circuit. This is shown in FIG. **12**.

In the "totally transferred" arc plasma, there is also only one electrical circuit. Here, however, all the current intensity is transmitted from the cathode to the piece being processed which is connected as anode through the plasma jet coming out from the nozzle. In this case, the nozzle acts exclusively as constricting element for the plasma column without forming part of the electrical circuit according to FIG. **11**.

A "mixed or coupled" arc plasma is obtained when both the nozzle and the workpiece are anodes in the electrical circuit in two parallel distinct lines. In the known art, such a connection results in the constricting nozzle acting as an auxiliary pilot anode according to FIG. **10**. In said combination, 5–30 percent of the total current passes through the auxiliary pilot anode, with the remaining 95–70 percent of current being transferred to the workpiece.

In any case, when the plasma-jet generating device is removed from the workpiece, the transferred arc will cease whereas the pilot arc remains. The transferred arc will light up again automatically with the reverse action of reapproaching the piece being processed with the device, by virtue of the pilot arc which acts as primer. Said type of coupled-arc plasma is more appropriately called "prevailingly transferred" arc plasma. In the known art, said plasma type is used in particular in "rapid-cut," and "saldospray" operations.

The first group of interchangeable inserts is shown assembled in FIG. **1** and isolated in FIGS. **2**, **2A**, **2B** and **2C**. FIG. **2A** shows the section along line AA and FIGS. **2B** and **2C** show the left and right hand end views, respectively. These inserts comprise the cathode **5**, the specially cooled anode **13**, the anode locking ring **14** with tube **24** for auxiliary gas feeding, which gas is blown in from the ring of holes **25**, and tube **16** for feeding the coating matter. This group is suitable for the "spray" and "saldospray" applications with plasma-jets of noble gas, preferably argon. The other features of this group of interchangeable inserts have been described with respect to FIG. **1**.

A second group of interchangeable inserts is shown in FIGS. **7**, **7A**, **7B** and **7C**. FIG. **7A** shows the section along line AA and FIGS. **7B** and **7C** show the left and right hand end views, respectively. These inserts comprise the cathode **5**, the specially cooled anode **13**, an internal anode adapter **26**, an external anode adapter **28**, locking ring **27**, and a feeding tube for the coating matter **16**, the other features being the same as previously shown. This group of inserts is suitable for "-spray" applications with the use of non-noble gas plasma-jets such as nitrogen and/or hydrogen, and preferably nitrogen.

A third group of interchangeable inserts is shown in FIGS. **8**, **8A**, **8B** and **8C**. FIG. **8A** shows the section along line AA and FIGS. **8B** and **8C** show the left and right hand end views, respectively. These inserts comprise the cathode **5**, the specially cooled anode **13**, an internal anode adapter **26**, an external anode adapter **28**, a locking ring **27**, a feeding tube **16** for the coating matter, a tube **24** for delivery of auxiliary gas (nitrogen and/or air, preferably nitrogen), said gas being blown in from a ring of milled channels **29**, and from the external ring of openings **30**. The other features are as previously shown. This group of interchangeable inserts is suitable for "plastospray" applications with the use of plasma-jets of non noble gas consisting of nitrogen and/or hydrogen, preferably nitrogen.

A fourth group of interchangeable inserts is shown in FIGS. 9, 9A, and 9B. FIGS. 9A and 9B show the respective left and right end views of FIG. 9. This group comprises the cathode 5, the specially cooled anode 13, only one anode adapter 26, and a locking ring 27 which also has the function of distributing the auxiliary gas which can be introduced through tube 24, fixed on the anode adapter, and can be blown in through the ring of holes 31 which latter may also be arranged on the front face of the anode nozzle 13. The other features are the same as previously described. This fourth group of interchangeable inserts is suitable for "rapid-cut" applications, using as the arc gas argon or mixtures of argon/nitrogen and argon/hydrogen, and preferably mixtures of argon/nitrogen comprising 95–25 percent of argon and 5–75 percent of nitrogen, with particular preference to the restricted range of 80–50 percent of argon and 20–50 percent of nitrogen.

While in all four of the above-cited groups of inserts the geometry of the water-cooled cathodic surfaces has remained the same as that according to U. S. Pat. No. 3,390,292 (i.e. direct cathode cooling by injection of the cooling water normally and centrally at the cathode rear surface), the geometry of the cooled surfaces of anode 13 has been changed and improved so that the water is conveyed in equicurrent with the plasma-jet and is forced onto holed heat exchange surfaces 32 and 32' having cylindrical or conical geometrical configuration, said surfaces being coupled with other heat exchanging surfaces 33, 33' and 33'', consisting of annular groove or grooves through which groove or grooves the water is directed towards the discharge, as is shown in FIGS. 2, 7, 8 and 9.

More particularly the anode (see FIGS. 1, 2, 2A, 2B and 2C) has been improved according to a new design in which the position of the ring of holes and of the groove, with reference to the anode of U. S. Pat. No. 3,390,292, is inverted so that the water coming from the interelectrodic electro-insulating element is entering, multiradially circumferentially and equidirectionally to the plasma-jet, through a ring of holes 32 which is placed in the inner part of the anode, coaxially to the plasma generator. In this way the water forced into the holes 32 reaches the anodic surfaces to be cooled, developing a better cooling effect by more vigorous striking action of the water jets, and finally leaves out through the transverse groove 33, moving multiradially, centrifugally and obliquely in a countercorrent to the plasma jet towards the discharge collecting sump 12.

According to another object of the invention, the anode is substituted with an insert of two pieces, the first of which is an anode adapter while the second is the true anode. The anode can be provided with a set of holes and grooves longitudinally placed in form of ring inside the body of the anode and coaxially to the nozzle of the same. With reference to the insert of FIGS. 9, 9A, 9B, the anode body 13 has no longitudinal holes or grooves, but only one transverse groove 33. In the anode adapter 26 instead are present a conical hole in the center and two distinct truncated conical rings of holes which are coaxial each other and to the central conical hole. Through the holes 32 of the inner conical ring the water is forced reaching so the anode 13 and striking vigorously the inner surfaces 32''. After the U-turning in the groove 33, the water leaves out to the discharge, passing in opposite sense to plasma-jet through the holes 33'' of the outer conical ring of the anode adapter 26. In this way the anode 13 reaches a higher heat-resistance, because the anode adapter develops a more efficient cooling action. Another advantage is that plasma-jets of higher power may be developed.

With reference to the inserts of FIGS. 7, 7A, 7B, 7C and FIGS. 8, 8A, 8B and 8C, the anode body 13 has longitudinal holes 32', longitudinal grooves 33' and transverse groove 33. Finally the anode body 13 is covered in the right side by an external anode adapter 28, and in the left side by the anode adapter 26. In the anode adapter 26 are present a cylindrical hole in the center and two distinct truncated conical rings of holes which are coaxial each other and to the central cylindrical hole. The water coming from the holes 32 of the inner truncated conical ring of the anode adapter strikes into the holes 32', of the anode equidirectionally with the plasma-jet and turning in the groove 33, flows in opposite sense to plasma-jet through the longitudinal grooves 33' in the anode, in countercurrent to the plasma-jet, leaving out the anode by discharge through the holes 33'' of the anode adapter 26. In this way the cooling action of the water on the anode is made more efficient and consequently higher the resistance of the anode.

Hereinafter, the geometry of the electrode surfaces, in contact with the plasma-jet, will be described, in any insert, the tip ending cathode is coaxially placed inside the conical part of the nozzle.

For the group of inserts according to FIG. 2, suitable for noble gas plasma-jets, preferably of argon, the tapers of the cathode and of the nozzle are between 53° and 63°, and between 61° and 71°, respectively, and preferably 58° for the cathode and 66° for the nozzle. In this group of inserts, the conical end of the cathode is cropped, with a bending radius between 0.75 and 1.5 mm, and preferably 1.25 mm.

For the group of inserts according to FIGS. 7 and 8, suitable for nitrogen and/or hydrogen plasmas, preferably nitrogen plasma, the tapers of the cathode and of the nozzle are between 85° and 95°, and between 54° and 64°, respectively, and preferably 90° for the cathode and 59° for the nozzle. For the group of inserts according to FIG. 9, suitable preferably for mixed plasmas of argon/hydrogen or even more preferably for argon/nitrogen, the tapers of the cathode and of the nozzle are between 35° and 45°, and between 18° and 22°, respectively, and preferably 40° for the cathode and 20° for the nozzle.

For the groups according to FIGS. 7, 8 and 9, the cathode taper is crop-ended with a flat face, being normal with respect to the axis, having a diameter comprised between 1.4 and 1.8 mm, preferably 1.6 mm. For the insert groups of FIGS. 2, 7 and 8, the distance at which the cathode is tightened, within the nozzle taper, is such that the cathode tip will appear coplanar with the beginning of the cylindrical portion of the nozzle within a variance range of ± 2 mm. For the insert group of FIG. 9, on the other hand, the distance at which the cathode is tightened, within the nozzle taper, is such that the cathode tip is between 5 and 10 mm from the external tip of the nozzle, and preferably 6 mm.

FIG. 10 shows a diagram for arc plasma for the "-prevailingly transferred" type. In this figure, line 101 shows the entry of water and current into cathode compartment 105 while line 102 shows the exit of water and current coming from anode compartment 106. Also shown is anode line 103 which is connected to workpiece 114. The interelectrode electro-insulator of the plasma-jet generator device is shown at 104 between the cathode compartment 105 and anode compartment 106. The auxiliary ignition electrode 107, powered by ignition generator 108, which is fed by the alternate electric current feed line 115, ignites the plasma generator per se. At 109 is seen a variable rheostat with water cooling. The resistance in this rheostat is made high so that the current will pass on to line 103 to give a "prevailingly transferred" arc plasma. At 110 is a connecting anode line and 111 is the line for reentrance into electric current rectifying machine 113 fed by three-phase alternating current feed line 116. The cathode line from machine 113 is seen at 112.

In FIG. 11, which shows a diagram of "totally transferred" arc plásma, those features referred to in FIG. 10 are equally applicable. This figure has been modified in that a fuse 117 has been inserted into the connecting anode line 110 which fuse, at ignition of the plasma-jet, interrupts the passage of current through the anode line 110 so that all can well pass through line 103 to the workpiece 114, being processed. Thus there is a "totally transferred" arc plasma.

FIG. 12 relates to a diagram for a "non-transferred" arc plasma. Again, those things stated as to FIG. 10 are equally applicable. It should be noted, however, that workpiece 114 has no electrical connection whatsoever thereto. Anode line 103 is connected to anode line 102, cutting out rheostat 109 from the circuit. Line 110 is also disconnected so that rheostat 109 is completely disconnected.

minimum diameters of 110 mm and even smaller, when using the device in the "head" version with plasma-jet at 45°; moreover, the inspection and the maintenance of the cathode has been improved through the two-fold possibility of extracting it both from the front and from the rear as is seen in FIGS. 3 and 4. Finally, complementary air cooling has been combined with the water cooling of the interelectrodic electro-insulating element of the Perugini generator to provide a more efficient cooling of the element, which is particularly delicate and sensitive to heat because it consists of macromolecular organic material, and the possibility therefor of employment in overheated working ambients.

The improvement in efficiency and elasticity of the use is obtained by means of an interchangeable set of electrode groups, each group comprising a cathode and a nozzle. Owing to the better cooling, the plasma-jet generator is able to operate in a range of power densities from 0.5 up to 4.5 kW/mm², and with ratios of power/arc gas flow, exceeding 10 and up to 30 kW/m³/h.

The above-identified structures of the improved plasma-jet generating device having high elasticity of operation, just by virtue of their surprising functional capacity, allow distinct applications characterized by more intense loads and densities of energy, thus offering applications of greater practical utility. Merely exemplifying and not limiting, we give hereinbelow examples of the different applications of the improved generator. The main operating data for these examples are summarized in table I. In order to complete the data reported in table I, some details will be given in what follows, relating to each of the examples and referring to the type of application and to the result obtained in each test, with respect to particular conditions of examination.

TABLE I

	Protective coating operation				Rapid-cut operation		
Example number	1	2	3	4	5	6	7
Nozzle diameter, mm	5	5.5	5	6.5	3	3	3.
Arc gas	Nitrogen	Argon	Nitrogen	Argon	Argon with 50% N_2.	Argon with 33.3% N_2.	Argon with 33.3% N_2.
Current density of anode nozzle, amp/mm.²:							
Total	12.75	25.5	13.26	13.64	38.2	41	42.2.
Transferred				12.11	31.8	34.6	35.3.
Power density of anode nozzle, kw./mm.²:							
Total	1.15	0.89	1.06	0.518	3.49	3.48	3.99.
Transferred				0.461	2.90	2.94	3.32.
Ratio: Total power/arc gas flow, kw./m.³/h.	12.5	15.33	12.01	11.88	17.56	20.55	18.8.
Type of application	S	S	P.S	S.S	Ra.C	Ra.C	Ra.C.
Type of electrode coupling, Fig	7	1	8	1	9	9	9.
Type of connection to apparatus, Fig	12	12	12	10	10	10	10.
Type of metal subjected to operation	Aq. 42	AISI-304	Iron A-100	Aq. 42	Aluminum	Copper	Stainless steel.
Dimensions of metal subjected to the operation, mm	Lamina 60 × 50 × 5.	Lamina 60 × 50 × 4.	Tube φ200-h50	Plate 350 × 40 × 15.	Sheet S=10	Sheet S=10	Sheet S=10
Cutting rate, cm./l					170	92	34.
Coating matter in powder form	Al_2O_3	ZrO_2	Polyethylene resin.	Nickel chrome			
Granulometry of the coating matter, mesh	−325 +500	−270 +400	−150 +325	−150 +270			

LEGEND: S=Spray. S.S.=Saldospray. P.S.=Plastospray. Ra.C.=rapid cut.

The advantages obtained with the plasma-jet generator according to our invention can be summarized as follows: the overall dimension has been remarkably reduced so as to permit the use of the device of the generator inside of small tubular elements, down to

EXAMPLE 1

A 0.25 mm thick coating of Al_2O_3 was produced to give an electrical insulation good even at 500°C. After having kept the thus prepared specimen in a muffle for 4 hours at the temperature of 500°C in air atmosphere,

the degree of electrical insulation was checked. The insulation was fully positive when repeatedly touching the various zones of the applied coating with the tips of an electrotecnical tester.

EXAMPLE 2

A 0.35 mm thick coating of ZrO_2 stabilized with about 4.5% of CaO was produced to give a barrier against heat oxidation, resisting to actions of sudden thermal shock. The results was fully positive since the prepared specimen withstands, without any damage to the applied coating, a series of thermal shocks (more than 20), carried out by directing from a distance of 5 cm an oxyacetylene jet (0.275 l/sec. for C_2H_2 ; 0.265 l/sec. for O_2 at 17°C and 746 mm Hg) on the front of the specimen and bringing the temperature of the metal mass up to around 500°C. At this point, a sudden direct jet of water at 15°C was applied. This cylindrical succession of hot and cold jets was repeated. The surface temperature of the ceramic coating, when the metal mass had a temperature of 500°C, was about 1,500°C at the central point hit by the oxyacetylene jet.

EXAMPLE 3

A 0.5 mm thick coating of polyethylene material was produced to provide a protection against corrosion from saline bath. The result of the protection has appeared positive since the specimen remained in perfect state both as to its immersed part and to the part emerging from the saline bath during the corrosion tests wherein it had been kept for over 1,000 hours at room temperature.

EXAMPLE 4

A 0.05–0.1 mm thick coating of chrome nickel 20–80 in the form of a strip about 4–5 mm large, was formed during each pass on the base element to which the coating matter binds itself by the surface welding phenomenon. The coating thus achieved perfectly resists bending in an arch having a 280 mm radius.

EXAMPLES 5, 6, and 7

The result of cutting different metals under consideration, appears improved by the complete elimination of the burrs, in particular on the lower borders, and by a cut wall which appears particularly vertical in the cutting of stainless stell, and particularly smooth in the cutting of copper.

We claim:

1. In a plasma-jet generator, comprising a cathode, an interelectrodic electroinsulating element, an anode, said cathode and anode being coaxial electrodes, means for injecting a stream of water against the rear of the cathode, multiradial directrixes determined by the rear configuration of the cathode for passage of water to circumferential water passages in the electroinsulating element for conveying the cooling water through said element to the anode, said passages being coaxial to the electrodes and equidirectional to the plasma-jet, and means for passing cooling water around the anode to cool the same, and means for collecting the water leaving out the anode into a circular discharge collecting sump so that the water entering the anode and the discharge collecting sump are adjacent each other though separated from each other by an annular diaphragm supporting the anode; the improvement comprising a resistant anode, which on an integral copper body and in a coaxial position to a central nozzle, said nozzle has a truncated conical ring of holes in a first portion of said anode through which the cooling water flows circumferentially coaxially and equidirectionally with the plasma-jet and with a centripetal movement, then striking and cooling the inner wetted surface of said anode and finally discharging through a transverse groove, according to a multiradial centrifugal and oblique direction, towards a discharge collecting sump.

2. The plasma jet generator of claim **1**, wherein the anode is substituted by an insert comprising at least two pieces, the first of which is an anode adapter and the second of which is the true anode, wherein at least the anode adapter, having in its center a cylindrical or frusto-conical hole, is also provided with a double frusto-conical ring of holes, the central hole and the rings of holes being coaxial each other and to the plasma generator, in said insert, so that the water coming from the interelectrodic electro-insulating element is forced inside the holes of the inner frusto-conical ring towards the anode, and is discharged from the anode through the holes of the outer frusto-conical ring of the anode adapter.

3. The insert according to claim **2**, wherein the anode has holes and grooves longitudinally placed in form of ring inside the body of the anode and coaxially to the nozzle of the same, so that the water flows through the holes equidirectionally with the plasma jet and flows in the grooves countercurrently to the plasma jet.

4. The insert according to claim **2**, wherein the anode has only a transverse groove.

5. The plasma-jet generator of claim **1**, wherein the internal conformation generated by the electrodic inserts and in contact with the arc gas presents a coaxial cylindrical cathode ending in only one tip taper, within a conical part constituting the inside of a cylindrical nozzle.

6. The plasma-jet generator of claim **5**, wherein when using plasma-jets originated by a noble gas, the taper of the cathode and that of the nozzle are between 53° and 63°, and 61° and 71°, respectively.

7. The plasma-jet generator of claim **6**, wherein the preferred taper values of the cathode and of the nozzle are 58° and 66°, respectively.

8. The plasma-jet generator of claim **7**, wherein the tip of the cathode is cone shaped and cropped with a bending radius between 0.75 and 1.5 mm.

9. The plasma-jet generator of claim **7**, wherein the bending radius is 1.25 mm.

10. The plasma-jet generator of claim **3**, wherein when using plasma-jets originated by a gas selected from nitrogen, hydrogen and mixtures thereof, the taper of the cathode and that of the nozzle are between 85° and 95°, and 54° and 64°, respectively.

11. The plasma-jet generator of claim **10**, wherein the preferred taper values of the cathode and of the nozzle are 90° and 59°, respectively.

12. The plasma-jet generator of claim **4**, wherein for use of plasma-jets originated by gaseous mixtures selected from argon/nitrogen and argon/hydrogen, the cathode taper and that of the nozzle are between 35° and 45°, and 18° and 22°, respectively.

13. The plasma-jet generator of claim **12**, wherein the preferential taper values of the cathode and of the nozzle are 40° and 20°, respectively.

14. The plasma-jet generator of claim 13, wherein the cone-shaped tip of the cathode is cropped with a flat face being normal with respect to the axis of said cathode, said flat face having a diameter comprised between 1.4 and 1.8 mm.

15. The plasma-jet generator of claim 14, wherein the diameter is 1.6 mm.

16. The plasma-jet generator of claim 8, wherein the position of the cathode tip is coplanar with the beginning of a cylindrical portion of the nozzle, within a variance of ± 2mm.

17. The plasma-jet generator of claim 11, wherein the position of the cathode tip is coplanar with the beginning of a cylindrical portion of the nozzle, within a variance of ± 2 mm.

18. The plasma-jet generator of claim 14, wherein the coaxial assemblage of the cathode with respect to the nozzle is separated at a distance between 5 and 10 mm.

19. The plasma-jet generator of claim 18, wherein the separation is 6 mm.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,684,911 Dated August 15, 1972

Inventor(s) GIANCARLO PERGUINI et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading to the printed specification, there should be included --Assignee: Montecatini Edison S.p.A., Milan, Italy

Signed and sealed this 18th day of December 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

RENE D. TEGTMEYER
Acting Commissioner of Patents