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G. M. GIANNINI ET AL
HIGH-INTENSITY ELECTRICAL PLASMA-JET TORCH
INCORPORATING MAGNETIC NOZZLE MEANS

2,944,140

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2 Sheets-Sheet 1

FIG. 1.

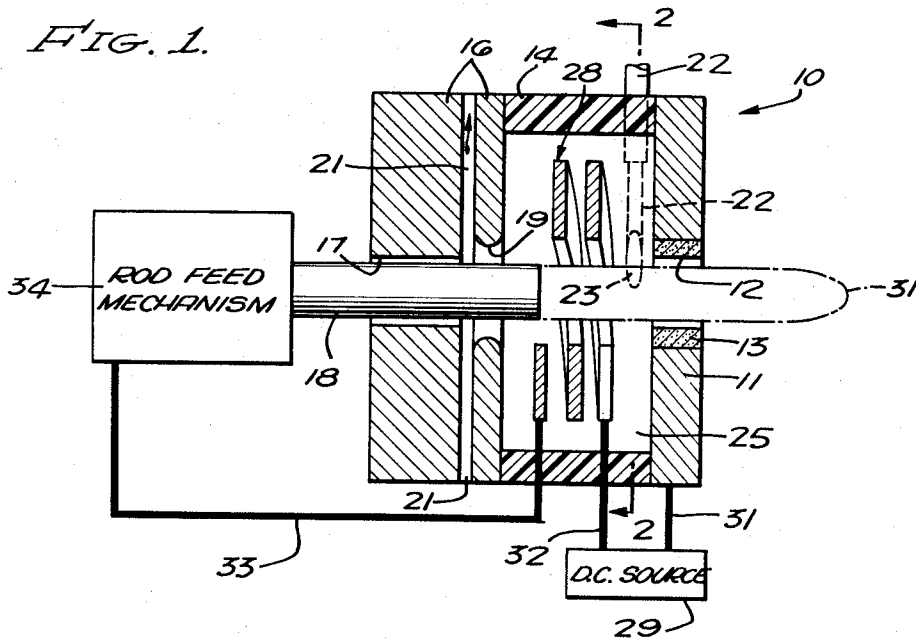


FIG. 2.

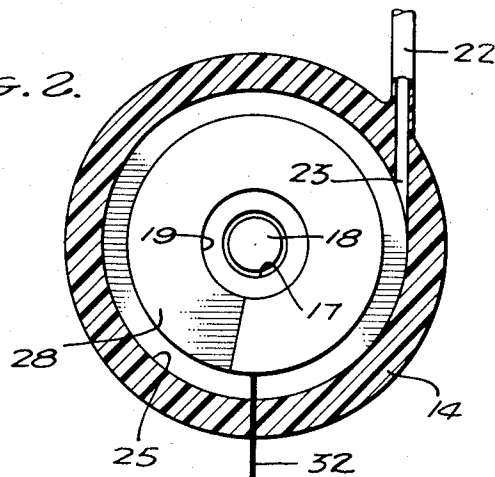
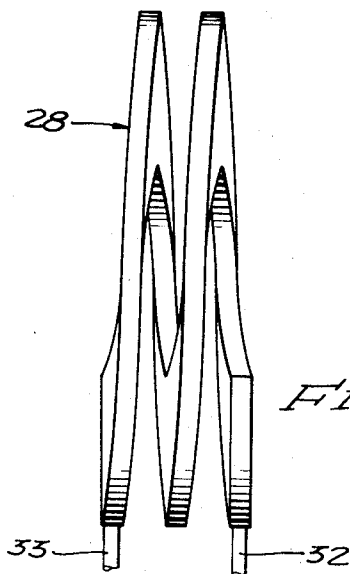


FIG. 3.



GABRIEL M. GIANNINI
VERNON H. BLACKMAN
INVENTORS

BY *Richard L. Giannini*

ATTORNEY

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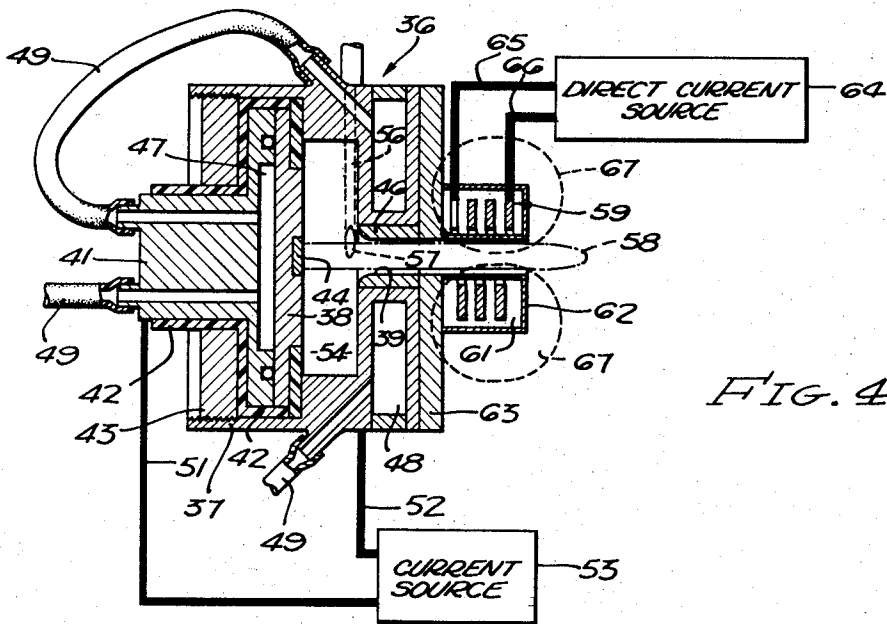


FIG. 4.

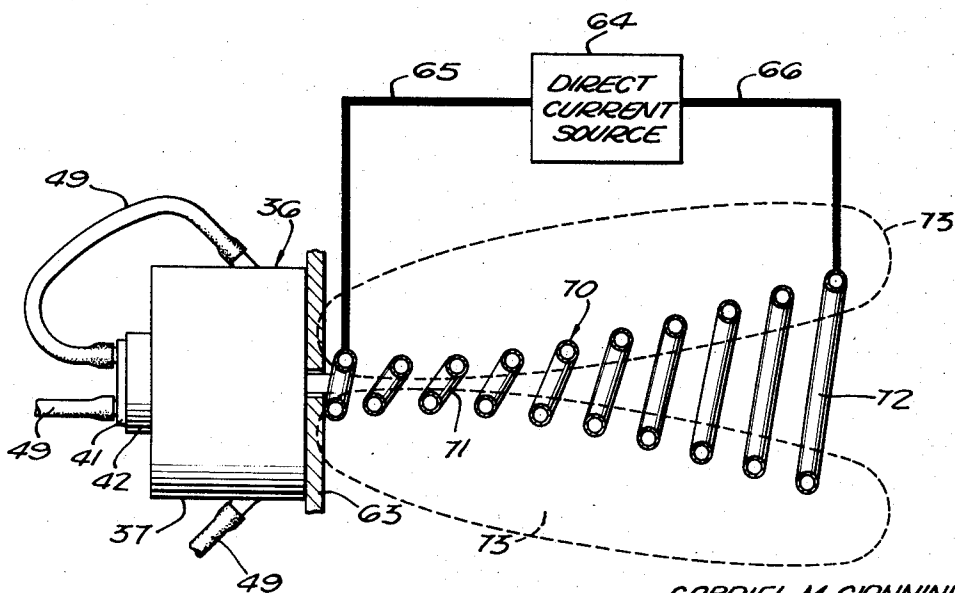


FIG. 5.

GABRIEL M. GIANNINI
VERNON H. BLACKMAN
INVENTORS

BY *Richard H. Schwartz*

ATTORNEY

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2,944,140

**HIGH-INTENSITY ELECTRICAL PLASMA-JET
TORCH INCORPORATING MAGNETIC NOZ-
ZLE MEANS**

Gabriel M. Giannini, Newport Beach, and Vernon H. Blackman, Laguna Beach, Calif., assignors to Plasma-dyne Corporation, Santa Ana, Calif., a corporation of California

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17 Claims. (Cl. 219-123)

This invention relates to a torch adapted to generate high-temperature plasma by means of an electric arc, and incorporating magnetic nozzle means. The invention further relates to a method of stabilizing and concentrating the hot ionized gas generated in a high-intensity plasma torch.

High-intensity electrical plasma-jet or plasma-flame torches are adapted to generate high-temperature plasma by means of an electric arc which is constricted in order to increase the current density thereof. As here employed, the word "plasma" is intended to denote neutral gas, ions and electrons at high temperatures, and is not employed in the sense of meaning a fully ionized gas. Such torches for producing high-temperature plasma may present problems of arc and plasma stability. Furthermore, a large amount of the heat present in the arc and plasma is necessarily transferred to the casing of the torch and to the coolant fluid passed therethrough, as well as to the atmosphere, which decreases torch efficiency.

In view of the above and other factors characteristic of high-intensity electrical plasma-jet torches, it is an object of the invention to provide an apparatus and method for producing a magnetic nozzle action which stabilizes the plasma and also concentrates the same to thereby reduce heat transfer and improve efficiency.

A further object of the invention is to provide a method and apparatus for generating a magnetic field closely adjacent the high-temperature plasma, such field having strong axial and radial components to create a magnetic nozzle effect.

A further object of the invention is to provide magnetic nozzle means located within the body of a high-intensity electrical plasma-jet torch.

A further object is to provide magnetic means located forwardly of the nozzle electrode of a high-intensity plasma-jet torch and shaped to provide strong axial and radial magnetic field components to produce a nozzle action.

A further object is to provide magnetic nozzle means located forwardly adjacent the nozzle electrode of a high-intensity plasma torch, in combination with magnetic shield means for preventing entrance of the lines of the magnetic force into the torch.

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

In the drawings:

Figure 1 is a schematic longitudinal central sectional view illustrating a high-intensity plasma torch incorporating magnetic nozzle means within the body thereof;

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

Figure 3 is a fragmentary side elevation illustrating the generally helical coil which produces the magnetic nozzle action;

Figure 4 is a schematic longitudinal central sectional

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view illustrating magnetic nozzle means located forwardly adjacent the nozzle electrode; and

Figure 5 is a schematic view, partially in side elevation and partially in longitudinal central section, illustrating another embodiment of magnetic nozzle means located forwardly of the nozzle electrode.

Referring first to the embodiment of Figures 1-3, an electrical plasma-jet or plasma-flame torch is illustrated schematically at 10 as comprising a generally disc-shaped nozzle electrode 11 having a central cylindrical nozzle opening 12 the wall of which is formed by a tube or insert 13 of carbon. A generally cup-shaped casing is provided adjacent the nozzle electrode 11 and is indicated schematically as comprising a tubular or hollow cylindrical side wall 14 formed of insulating material. The bottom wall of the casing is generally disc-shaped and is indicated at 16, having at its outer portion a central opening 17 through which a carbon electrode rod 18 is inserted. The inner portion of wall 16, relatively adjacent the nozzle, is formed with an opening 19 the diameter of which is larger than that of the nozzle opening. Such large opening 19 communicates with a plurality of radial water passages 21.

A tangential water inlet conduit is indicated at 22 and communicates through an opening 23 with the cylindrical or annular chamber 25 which is formed within the casing side wall 14. Water introduced tangentially through conduit 22 and opening 23 whirls rapidly in the chamber 25 and then is discharged through the opening 19 and through the radial passages 21 to a suitable drain, not shown. No water passes through the nozzle opening since the diameter of the opening 19 determines the diameter of the vortex in the whirling water. The whirling water does not touch the rod electrode 18. Openings 12, 17 and 19, and chamber 25, are coaxial.

Means are provided for creating a generally nozzle-shaped magnetic field having strong axial and radial components, and closely surrounding the arc and plasma passing between the end of electrode rod 18 and the carbon insert 13 in the nozzle electrode. Such means are illustrated schematically as comprising a relatively short coil or solenoid 28 disposed in chamber 25 coaxially of the nozzle opening. The inner portions of the coil are located relatively adjacent the electric arc, such arc being constricted to the vortex in the whirling water. The illustrated coil 28 has a rectangular cross-section and is shaped helically, somewhat in the manner of a cork screw. The coil 28 is cooled by the whirling water passed through chamber 25.

A current source, indicated schematically at 29, is provided and is capable of delivering very high currents although the voltage need not be great. For example, the range of currents may be between 100 and 10,000 amperes, at a voltage between 50 and 500 volts. The source 29 should be adapted to deliver relatively steady direct current.

One terminal of source 29 is connected through a lead 31 to nozzle electrode 11, whereas the other source terminal is connected through a lead 32 to one end of coil 28. The other end of the coil is connected through a lead 33 and through a rod-feeding mechanism, schematically indicated at 34, to the electrode rod 18. Such rod-feed mechanism is adapted to feed the electrode 18 forwardly to compensate for burning of the end thereof.

It is emphasized that the coil 28 has such a size, shape and location that the lines of magnetic force or flux passing therethrough have strong axial and radial components. A magnetic throat or nozzle passage is thus provided within the torch, which has the effect of stabilizing the electric arc and the plasma, and of concentrating the arc and plasma at the axis of the torch so that heat transfer to the whirling water in chamber 25

and to the torch components is minimized for maximum torch efficiency. The magnetic field also tends to accelerate the plasma. The magnetic nozzle or constriction action is indicated schematically in Figure 4 with relation to a coil located forwardly of a nozzle, as distinguished from within the torch. In Figure 4, the lines of magnetic force are indicated by dashed lines.

Description of the method particularly with relation to Figures 1-3

Stated generally, the method comprises providing a high-intensity constricted electric arc between nozzle and back electrodes to effect rapid flow of a high-temperature plasma jet out through the nozzle opening. Magnetic lines of force having strong axial and radial components are then generated coaxially around the plasma and are shaped as a throat or nozzle to stabilize the plasma and reduce heat transfer therefrom. In the embodiment of Figures 1-3 such magnetic throat or nozzle is located within the torch, whereas in the embodiments of Figures 4 and 5, the magnetic throat is located exteriorly of the torch.

With particular reference to the embodiment of Figures 1-3, the method comprises introducing water rapidly through conduit 22 and inlet opening 23 into annular chamber 25 for vortical flow therein and subsequent outflow through opening 19 and radial passages 21. The current source 29 is then turned on, and an electric arc is struck between electrode 18 and tube 13, being initiated by a suitable means which may comprise a stick of graphite inserted therebetween. A very high current, on the order of hundreds or thousands of amperes, then flows through a series circuit comprising source 29, lead 32, coil 28, lead 33, rod-feed mechanism 34, electrode 18, the electric arc, tube 13, electrode 11, lead 31 and source 29.

The high current flowing through the above-described circuit is constricted to the vortex in the whirling water, and is further constricted within such vortex because of the magnetic nozzle action previously indicated. In this connection, it is pointed out that the coil 28 is relatively short, and relatively close to the electric arc and to the plasma within the torch, so that the lines of magnetic force have very strong components in both axial and radial directions to create the desired nozzle shape.

The electric arc is therefore caused to have an extremely high current density, with consequent high-temperature plasma jet 31 which passes through the nozzle opening 12 at high velocity. As previously stated, the stability of the arc and the jet are improved by the magnetic nozzle action, and the heat transfer to the cooling water and the torch components is minimized so that the temperature of the jet is a maximum for a given power input.

Embodiment of Figure 4

Figure 4, and also Figure 5, illustrate plasma-jet torches in which the electric arc is constricted by means of whirling gas instead of whirling water as was the case in the embodiment of Figure 1. It is emphasized, however, that this is not to be interpreted as an indication that gas and water are the equivalents of each other insofar as arc constriction, and related effects, are concerned. Instead, both gas and water-type torches are illustrated solely for the purpose of showing the applicability of magnetic nozzle means to these distinct types of plasma torches.

The torch 36 shown in Figure 4 comprises a nozzle electrode 36 which is generally cup-shaped, and a generally disc-shaped back electrode 38 disposed in the nozzle electrode coaxially of the nozzle opening 39 therein. Back electrode 38 is in electrical contact with a base 41, and both the base and the back electrode are insulated from the nozzle electrode by means of suitable insula-

tion 42. A retaining ring 43 is employed to maintain the parts in assembled relationship.

The back electrode is provided centrally with an insert 44 formed of a suitable refractory metal such as tungsten. The nozzle electrode is correspondingly provided around the wall of opening 39 with a tubular refractory metal insert 46. The inserts comprise the arcing portions of the electrodes, and are maintained cool by means of water chambers 47 and 48 through which water or other coolant is continuously passed via conduit means or hoses 49. An electric arc is maintained between the inserts 44 and 46 by means of current fed through leads 51 and 52 from a suitable current source schematically indicated at 53. Source 53 should be of a type adapted to deliver a high direct current.

An annular gas-pressure chamber 54 is formed between the arcing portions of the electrodes and coaxially of the nozzle opening. Gas is introduced into such chamber through a tangential passage 56 and inlet opening 57 from a suitable source, not shown, of gas under pressure. It is preferred that argon, or other oxidation-preventing gas, be employed except in situations where it is desired to study the characteristics and effects of air, for example.

The gas introduced through passage 56 and inlet 57 whirls rapidly in chamber 54 and then expands out the nozzle opening 39, a portion of the whirling gas being converted to high-temperature plasma by the electric arc. The arc is constricted by the whirling gas, when such gas is introduced at proper pressure and velocity, so that the arc is of the high-intensity high-temperature type. The result is that the plasma is extremely hot and flows through the nozzle opening at high velocity in the form of a jet indicated at 58.

In the present embodiment, the magnetic nozzle means to stabilize and concentrate the plasma is indicated as comprising a coil or solenoid 59 which may correspond to the one indicated at 28 in Figure 3 except that, in the present form, another turn is provided. The coil or solenoid 59 is located coaxially of the nozzle opening forwardly adjacent the same, and is disposed in a cooling chamber 61 defined by an annular wall means 62 through which cooling water may be continuously passed by suitable means, not shown. The inner diameter of the coil 59 is only slightly greater than that of the nozzle opening. A shield 63, formed of magnetizable substance such as soft iron, is provided in flatwise engagement with the outer surface of nozzle electrode 37 and has the effect of concentrating the magnetic field forwardly of the torch. The coil is supplied with high direct current, such as 1,000 to 10,000 amperes, from a source 64 through leads 65 and 66.

As previously stated, the relatively short coil disposed coaxially around the jet produces lines of magnetic force such as are indicated schematically at 67, and which have very strong axial and radial components to create a magnetic throat or nozzle through which the jet must pass.

In practicing the method with the embodiment of Figure 4, gas is introduced through passage 56 and opening 57 at high velocity, and flows vortically in chamber 54 and then out through nozzle opening 39 as previously indicated. The current source 53 is applied, and the arc is suitably initiated between inserts 44 and 46. Current source 64 is applied to energize coil 59 and create the magnetic field, schematically represented at 67, having strong axial and radial components to provide a nozzle or throat shape.

The described magnetic field operates to induce eddy currents in the gas or plasma forwardly adjacent the nozzle opening. This, in turn, operates to effect constriction of the plasma, with the most constriction occurring at the throat of the magnetic field. This causes higher energy densities to be present at the central portion of the plasma, and minimizes heat transfer losses. Furthermore, the plasma is stabilized.

Embodiment of Figure 5

In the embodiment of Figure 5, the torch 36 may be identical to the one shown and described with reference to Figure 4. However, in the present embodiment the throat or nozzle-shaped magnetic field is created by properly shaping or contouring the generating coil instead of by providing the relatively short coil previously described. Thus, a relatively long coil 72 may be disposed coaxially around the jet and forwardly adjacent the nozzle opening. Such coil may be connected to the leads 65 and 66 from the D.C. current source 64. The illustrated coil is of the tubular type through which cooling water may be passed continuously by suitable means, not shown.

It is pointed out that the rear end of coil 70 (adjacent shield 63) is relatively large, and that the coil converges forwardly to a throat 71. From the throat, the coil diverges forwardly until, at its forward end 72, the diameter may be much larger than that adjacent the torch. It is thus seen that, despite the length of the coil, the lines of magnetic force, schematically indicated at 73, have a throat at 71 and have strong axial and radial components on opposite sides of the throat.

Except for the shape and the length of coil 70, the method with relation to Figure 5 is the same as that described with relation to Figure 4. The relatively long coil 70 of Figure 5 is particularly suitable for applications in which the jet is introduced into an evacuated space and is therefore relatively long. In this manner, the jet of plasma may be properly controlled, stabilized, accelerated, concentrated and directed by the magnetic field.

It is pointed out that the lines of magnetic force in all of the embodiments diverge in opposite axial directions (both forwardly and rearwardly) from the magnetic throat (most constricted) portion. Thus, the field resembles a venturi and may be characterized as a magnetic venturi.

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

We claim:

1. In a plasma apparatus, electric means to generate a stream of plasma, and means to generate a strong magnetic field surrounding and adjacent at least a portion of said stream, the lines of magnetic force of said field being shaped generally as a venturi having a throat and having portions diverging in opposite directions from said throat axially of said stream, said magnetic venturi being coaxial to said stream whereby said stream passes there-through for stabilization and concentration thereby.

2. The invention as claimed 1, in which said means to generate said magnetic field includes a coil coaxial to said stream, and means to pass a large current through said coil.

3. An electrical plasma-jet or plasma-flame torch apparatus, which comprises a nozzle electrode having a nozzle opening therein, a back electrode spaced and insulated from said nozzle electrode, means to maintain a high-current electric arc between said electrodes in the region of said nozzle opening, means to surround said arc between said electrodes with fluid, at least a portion of said fluid passing at high velocity from said back electrode to and through said nozzle opening in the form of high-temperature plasma, and means to generate a strong magnetic field coaxially around a portion of said plasma, said magnetic field having generally axial components in said plasma and diverging in opposite axial directions from a throat.

4. The invention as claimed in claim 3, in which said fluid means is adapted to effect vortical flow of fluid around the arc and plasma between said electrodes to thereby constrict said arc and plasma to the vortex in the whirling fluid.

5. The invention as claimed in claim 3, in which said magnetic field-generating means comprises a current-carrying coil disposed coaxial with said plasma, and means to pass a large direct current therethrough.

6. A plasma torch, which comprises a nozzle electrode having a nozzle opening therein, a back electrode spaced and insulated from said nozzle electrode, means to define a fluid chamber between the arcing portions of said electrodes, means to maintain a high-current electric arc in said chamber between said back electrode and said nozzle electrode in the vicinity of said nozzle opening, means to continuously pass fluid through said chamber, a relatively short coil mounted in said chamber coaxially around said arc, and means to pass a high current through said coil to thereby generate a strong magnetic field having both axial and radial components in nozzle relationship around said arc.

7. The invention as claimed in claim 6, in which said fluid means comprises means to pass water vortically in said fluid chamber to thereby constrict said arc to the vortex in the whirling water, and in which said coil is disposed in said whirling water for cooling thereby.

8. An electrical plasma-jet apparatus, which comprises a nozzle electrode having a nozzle opening therein, a back electrode spaced and insulated from said nozzle electrode, means to maintain an electric arc between said electrodes in the vicinity of said nozzle opening, means to pass a fluid through the space between said electrodes whereby at least a portion of said fluid is heated by said arc and flows out through said nozzle opening in the form of a jet of high-temperature plasma, and means to create a nozzle-shaped magnetic field adjacent said nozzle electrode and on the side thereof remote from said back electrode, said field being coaxial with said jet and having strong axial and radial components at said jet.

9. A plasma-jet torch apparatus, which comprises a generally disc-shaped nozzle electrode having a nozzle opening formed centrally therein, a generally disc-shaped back electrode spaced and insulated from said nozzle electrode and coaxial with said nozzle opening, means to define an annular gas-pressure chamber between said electrodes and coaxial with said nozzle opening, means to introduce gas tangentially into said chamber for vertical flow therein and subsequent flow out said nozzle opening, means to maintain a high-current electric arc between said electrodes through the vortex in said whirling gas, means to cool said electrodes, a relatively short coil mounted adjacent said nozzle electrode on the side thereof remote from said back electrode, said coil being coaxial with said nozzle opening, and means to pass a high direct current through said coil to create a strong nozzle-shaped magnetic field forwardly adjacent said nozzle opening.

10. The invention as claimed in claim 9, in which magnetic shield means are provided between said coil and said nozzle electrode to maintain the lines of magnetic force forwardly of said nozzle electrode.

11. An electrical plasma-jet apparatus, comprising torch means to generate a rapidly-moving jet or stream of high-temperature plasma consisting of neutral gas, ions and electrons at high temperature, a relatively short solenoid disposed generally coaxially around said jet adjacent said torch means, and means to pass a large direct current through said solenoid to thereby generate in and around said jet a nozzle-shaped magnetic field having strong axial and radial components.

12. An electrical plasma-jet apparatus, comprising torch means to generate a rapidly-moving jet or stream of high-temperature plasma consisting of neutral gas, ions and electrons at high temperatures, and a coil mounted coaxially around said jet forwardly adjacent said torch means, said coil being shaped interiorly as a throat or nozzle to produce a correspondingly-shaped magnetic field upon passage of current through said coil.

13. An electrical plasma-jet torch, which comprises a

nozzle electrode having a nozzle opening therein, a back electrode spaced and insulated from said nozzle electrode, means to maintain a high-current electric arc between said electrodes in the region of said nozzle opening, means to pass fluid between said electrodes whereby at least a portion of said fluid is heated by said arc and passes through said nozzle opening in the form of a jet of high-temperature plasma, and a relatively long magnetic field-generating coil mounted coaxially around said jet on the side of said nozzle electrode remote from said back electrode, said coil having a throat portion formed therein to provide, upon energization of said coil, a corresponding magnetic throat through which said plasma jet must pass.

14. The invention as claimed in claim 13, in which said means to pass fluid between said electrodes comprises means to effect vortical flow of gas at a rapid rate therebetween to form a vortex coaxial with said nozzle opening.

15. The invention as claimed in claim 13, in which a magnetic shield is provided between said coil and said nozzle electrode.

16. A method of stabilizing and concentrating a jet of high-temperature plasma which travels at high velocity from the back electrode of a plasma torch and to and through the nozzle opening in the nozzle electrode of such torch, which method comprises forming a strong direct magnetic field coaxially around said jet of plasma and diverging in opposite axial directions from a throat.

17. In a method of stabilizing and concentrating the plasma discharge from the nozzle opening of an electrical plasma-jet torch, the steps of providing coaxially around said jet forwardly adjacent said nozzle electrode a magnetic field-generating coil shaped to create therein a generally nozzle-shaped magnetic field having a throat or constricted portion through which said jet must pass, and passing a strong direct current through said coil.

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