

Dec. 13, 1960

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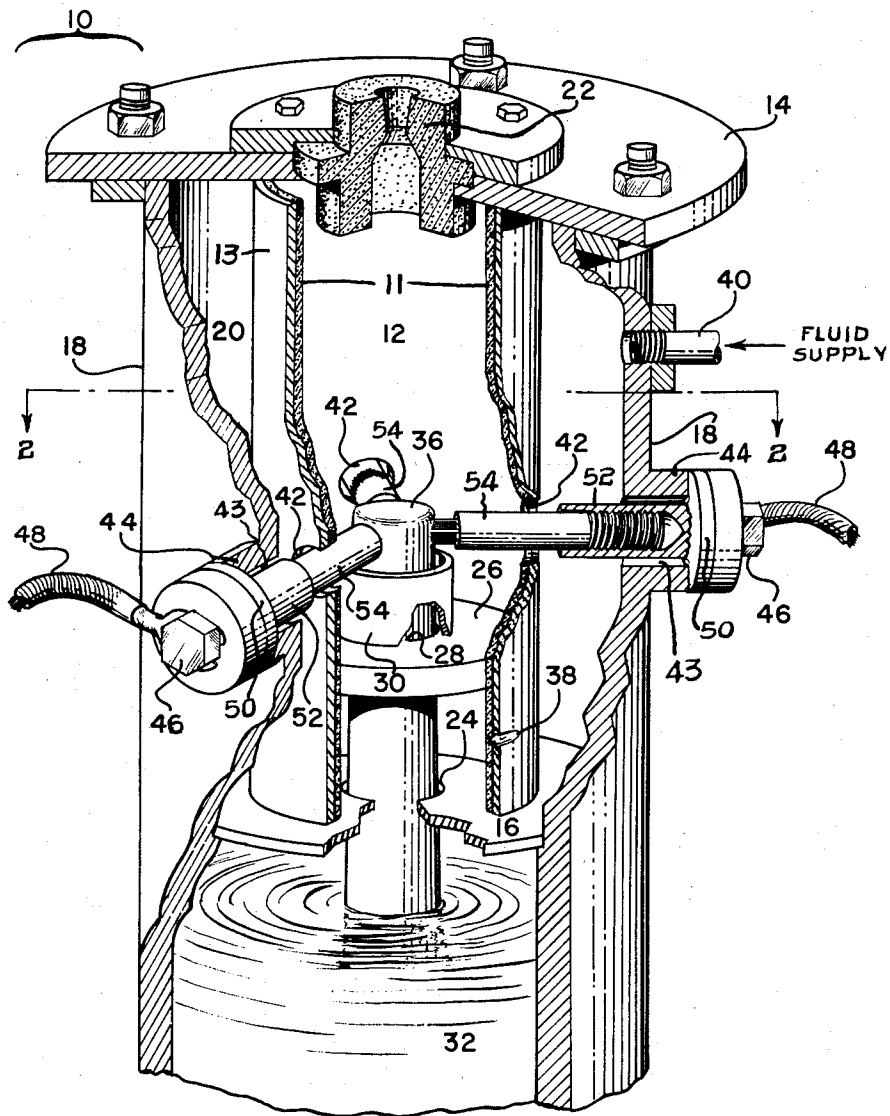
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ARC PLASMA GENERATOR

Filed June 26, 1959

3 Sheets-Sheet 1

FIG. 1.



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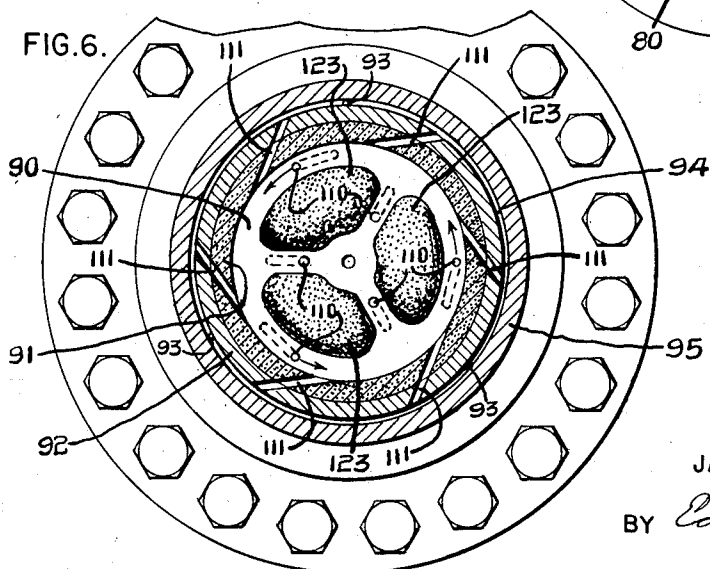
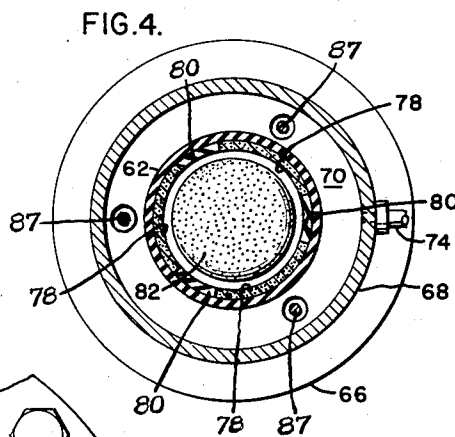
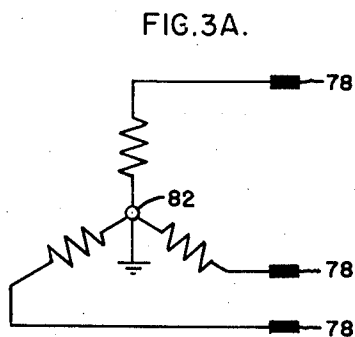
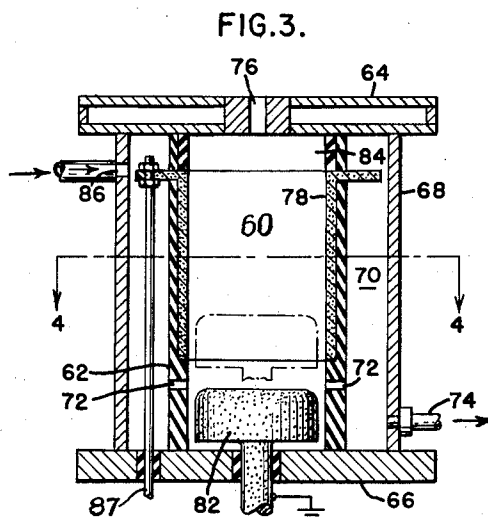
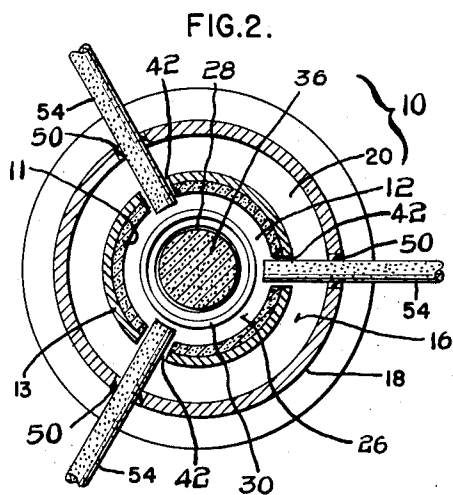
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ARC PLASMA GENERATOR

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3 Sheets-Sheet 2



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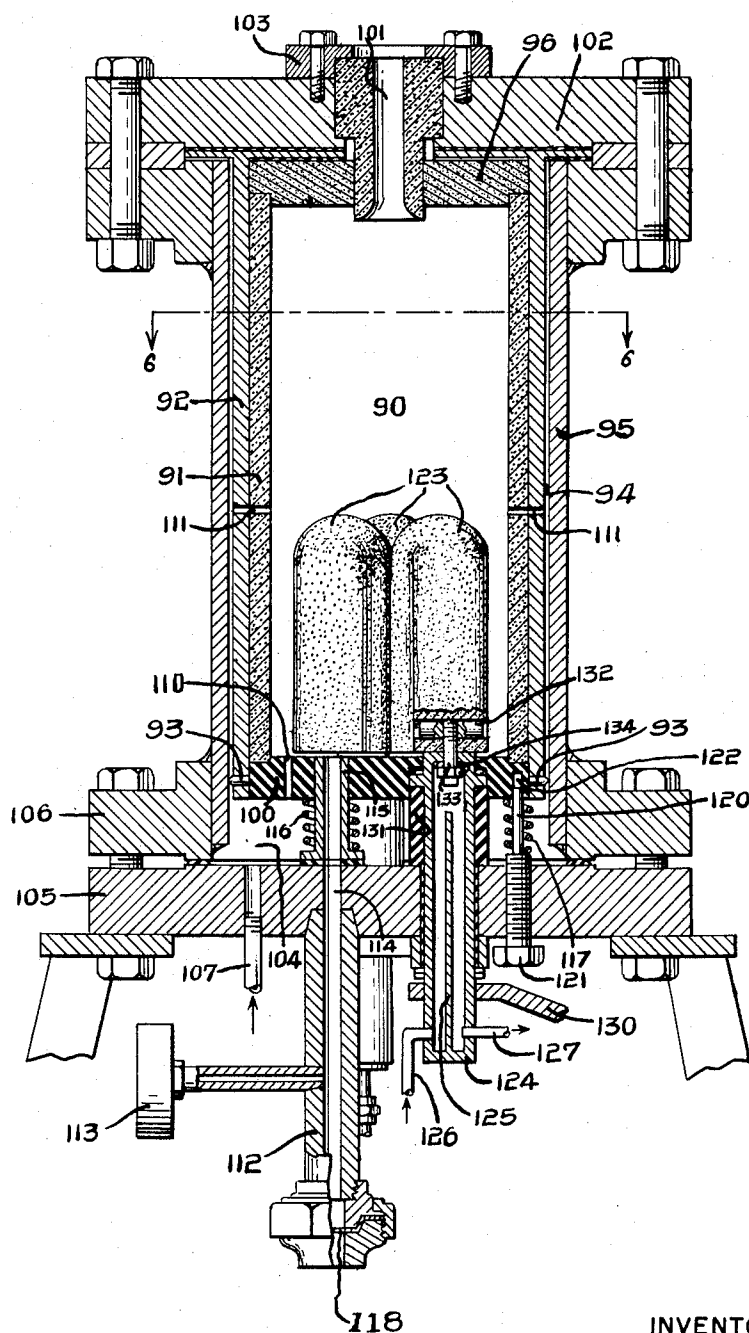
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ARC PLASMA GENERATOR

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3 Sheets-Sheet 3

FIG. 5.



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2,964,678

ARC PLASMA GENERATOR

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14 Claims. (Cl. 315—111)

This invention generally relates to improvements in plasma generators and more particularly to a plasma generator for producing a large volume of high temperature plasma from high-power electric arcs.

For purposes of the present invention, the term plasma, or arc plasma, means a partially ionized mass derived from air, or other gases such as oxygen, nitrogen, helium, etc., or from vaporized solids such as copper, iron, graphite, etc., or a mixture thereof, which is in such an extremely heated and excited condition that it does not obey the laws for low temperature ideal gases, $PV=RT$. It is known that the measurable temperature at the surface of the sun is about 10,000° F. or 5,000° Kelvin. The temperature of the plasma produced by an arc plasma generator, according to the present invention, is in this order of magnitude and is, therefore, capable of vaporizing any known material. For this reason, the plasma produced by such a generator may be advantageously employed for testing materials, particularly in the simulation of the conditions encountered in high-speed aerodynamics. Plasma generators may also be used for cutting, welding, metal spraying, and chemical processing. In the chemical processing area, arc plasma generators open the possibility for the production of new alloys and compositions and the processing of less commonly used materials which have not been readily workable by heretofore developed means.

Prior art arc plasma generators have produced a limited volume of plasma by continuously discharging an electric arc in a suitable working fluid; i.e., the material from which the plasma is to be produced. Where the electrical power inputs to such generators is in the lower kilowatt ranges, solid or liquid cooled electrodes have been employed with reasonably good results. However, such arc plasma generators cannot be scaled up to heat larger masses of working fluids by arcs in the megawatt (10^6 watts) power range with satisfactory results. One of the reasons the scaled up versions cannot be satisfactorily used with greater power inputs is that the rate of electrode erosion increases rapidly as the magnitude of the electric arc current increases. The rapid erosion of the electrodes in such scaled up generators reduces the operating time of such generators to periods of time of the order of one to two seconds, after which it is necessary to shut down the generator and replace the electrodes. One solution with small generators was that of feeding in the electrodes as they were consumed. In the larger generators with larger currents, the mechanisms and amount of insulation required makes this solution impractical.

Heretofore, the art has confined itself to the use of direct current in generating plasma. This is a sharply limiting factor, in view of the limited amount of direct current power that is available. Moreover, when a direct current source is used, it is necessary to insert a resistance or ballast in the circuit in order to stabilize the arc. This greatly reduces the power that is available for generating the arc itself. On the contrary, with alter-

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nating current source, the insertion of a resistance is unnecessary and a reactor may be employed instead, which does not waste power. It is therefore an object of this invention to provide an apparatus for producing high temperature plasma, which apparatus consumes alternating current, preferably multiphase alternating current.

Heretofore, arc plasma generators in the megawatt range have been limited in operation to a very short period of time such as two seconds and the like. Plasma generation for such a short period is highly limited in its usefulness, particularly for the purpose of testing aerodynamic models and the like. It is therefore an important object of this invention to provide an arc plasma generator in the megawatt power range which can operate for extended periods of time, far in excess of two seconds.

It is still another object of this invention to provide an extremely high current alternating current arc plasma generator capable of operation for a sustained period of time.

Another object of this invention is to provide such an arc plasma generator which is capable of producing a large volume of high temperature plasma over a sustained period of time.

It is another object to provide a high-power arc plasma generator which has a substantially longer period of operation between shutdowns for repair and replacement of the electrodes.

It is still another object of this invention to provide an arc plasma generator having a relatively low rate of electrode erosion.

It is still another object of this invention to provide an arc plasma generator which produces large volumes of high temperature plasma of controlled composition, in which the percentage of contamination by electrode materials is substantially reduced.

Other objects and many attendant advantages will more readily be comprehended by those skilled in the art after a consideration of the following detailed description of the invention and the drawings wherein:

Fig. 1 is a view in perspective showing a plasma generator embodying certain features of this invention, with certain parts broken away and shown in section in order more clearly to reveal important details.

Fig. 2 is a schematic view showing a section of the plasma generator, looking generally as indicated by the lines and arrows II—II which appear in Fig. 1.

Fig. 3 is a vertical sectional view of a modified form of plasma generator which embodies features of this invention.

Fig. 3a is a wiring diagram showing one manner in which alternating current is connected to operate the plasma generator shown in Fig. 3.

Fig. 4 is a sectional view of the apparatus shown in Fig. 3, taken as indicated by the lines and arrows IV—IV therein.

Fig. 5 is a vertical sectional view of a modified and preferred form of plasma generator constructed in accordance with this invention.

Fig. 6 is a section view taken as indicated by the lines and arrows VI—VI which appear in Fig. 5.

The following description uses specific terms for the sake of clarity. It is to be understood that such description is not intended to define or to limit the scope of the invention, but is, on the contrary, intended to be a description of those specific forms of the invention which have been selected for illustration in the drawings.

Turning now to the specific form of the invention shown in Figs. 1 and 2 of the drawings, the number 10 designates a plasma generator having a plenum chamber 12 formed by a graphite cylinder 11 which is maintained constantly under compression by an outer steel sleeve 13

which is heat-shrunk onto the outer surface of the graphite cylinder 11. The number 14 designates an upper face plate while the number 16 designates a lower face plate which is generally parallel to the plate 14. A strong coaxial outer cylinder 18 is provided forming a high pressure shell. The high pressure shell 18 is radially spaced from the plenum chamber 12 and forms an annular cooling chamber 20 completely surrounding the plenum chamber 12.

The upper face plate 14 is provided with a nozzle assembly 22 which is coaxial with the plenum chamber 12 and the high pressure shell 18, and has a suitable nozzle configuration for the purpose of emitting and directing the plasma jet that is generated. The nozzle itself is preferably composed of high temperature resistant graphite.

The lower face plate 16 is provided with a central circular opening 24 and is suitably secured to the outer cylinder 18. The lower extremity of the plenum chamber wall, formed by graphite cylinder 11 and steel sleeve 13, is secured to the surface of the lower face plate 16.

Axially spaced from the lower face plate 16, and located within the plenum chamber 12, is a spacer plate 26 which is rigidly secured to the interior surface of the wall of graphite cylinder 11. A central aperture 28 is formed within the spacer plate 26, coaxially with the aperture 24, and the spacer plate 26 is provided with a perpendicular cylindrical flange 30 which extends around the circumference of the central circular opening 24.

The number 32 designates a fluid cooling chamber which contains water or liquid air, for example. The fluid cooling chamber 32 is formed by the structural coaction of the outer cylinder 18 and a sealing member (not shown) spaced below the lower face plate 16. The cooling fluid may be introduced into and removed from the chamber 32 by any suitable means, not shown.

A rod electrode 36, composed of graphite, is coaxially supported within the plenum chamber 12 and serves as a ground or neutral connection. The electrode 36 is slidable axially through the apertures 24, 28 to protrude to the desired degree into the plenum chamber 12. The electrode 36 has a diameter which is slightly less than the diameters of the apertures 24, 28, providing spacing therebetween.

The number 38 designates one of a plurality of substantially tangentially angled apertures which are provided in the wall of the plenum chamber 12, below the spacer plate 26 but above the lower face plate 16. A fluid supply conduit 40 is provided in the wall of the outer cylinder 18 providing for the introduction of a fluid medium within the cooling chamber 20, for a purpose which will further become apparent hereinafter.

The wall of the plenum chamber 12 is provided with a plurality of coplanar and equally spaced apertures 42 (three in number as shown in Fig. 1) which are radially spaced from the end of the rod electrode 36. Coaxially with the apertures 42, a plurality of apertures 43 are provided in the outer shell 18, and are fitted with electrode mounting means 44. Each electrode mounting means 44 comprises a conductor connection 46 coupled into a suitable electrical coupling member 48, together with an insulating ring 50 which is provided between the connector 46 and the high pressure shell 18. The connector 46 is provided with a radial rod supporting member 52 forming an integral part of the conductor for supporting an electrode rod 54. Each electrode rod 54, which is composed of graphite or the like, is threaded in position and protrudes through the apertures 42, terminating at a point near but spaced from the rod electrode 36. As will be apparent, the electrode 54 is radially adjustable with respect to the supporting member 52 by simply threading the electrode in and out with respect to the supporting member 52. Each electrode 54 has a diameter which is slightly less than the diameter of the corre-

sponding aperture 42, providing a small clearance therebetween.

In operation of the embodiment shown in Figs. 1 and 2, fluid (usually gaseous) coolant is fed under pressure continuously through the conduit 40 into the cooling chamber 20. It flows inwardly through the angled apertures 38, then swirls spirally upwardly along the surface of the electrode 36 to the plenum chamber 12. The fluid also flows inwardly through the openings 42 around the electrodes 54 into the plenum chamber 12, further performing a cooling function. Additionally, the swirling movement of the coolant forms a constricting spiral which moves axially toward the nozzle 22, thereby constricting the arc and thereby producing a temperature of exceedingly high value in the plasma. The plasma is generated by striking an arc across from the electrodes 54 to the electrode rod 36, and the plasma thus generated is forcibly ejected under pressure through the nozzle 22.

The exceedingly high temperatures created by the formation of the plasma have a tendency rapidly to erode and even to break the graphite inner sleeve 11, but even should the graphite break sharply, it remains in place within the plenum chamber 12 because of the compressive effect exerted upon it by the outer sleeve 13, which is heat-shrunk onto the outer surface of the graphite cylinder 11. The graphite cylinder 11 shields the outer sleeve 13 by insulating it from the extreme heat of the plasma and continues to do so notwithstanding erosion or even breakage of the graphite. In turn, the cooling chamber 20 shields and insulates the outer pressure cylinder 18 from the heat of the plasma.

Referring now to the specific form of the invention shown in Figs. 3, 3a and 4 of the drawings, an arc chamber 60 is provided by means of an outer cylindrical wall 62 which is provided between an upper face plate 64 and a lower face plate 66. A high pressure shell 68 is coaxially provided with respect to the arc chamber 60, forming a cooling chamber 70 therebetween. Apertures 72 are provided in the wall of the arc chamber 60, connecting the arc chamber 60 with the cooling chamber 70. The high pressure shell 68 is provided with an outlet conduit 74 and an inlet conduit 86 for the purpose of circulating cooling fluid such as cold air or the like through the cooling chamber 70.

The upper face plate 64 is provided with an outlet nozzle 76 which is located coaxially with respect to the arc chamber 60 and the cooling chamber 70. It will be noted that the upper face plate 64 is hollow and that means are provided (not shown) for introducing and withdrawing the suitable cooling fluid such as water or the like.

The outer wall 62 of the arc chamber 60 is preferably composed of an electric insulator such as ceramic or the like. Disposed immediately adjacent to and within the outer wall 62 are a plurality of spaced graphite plates 78 which are insulated from one another by intermediate spacers 80. The spacers 80 are also located against the inner surface of the outer cylindrical wall 62 and serve as locking means for holding the plates 78 in their predetermined location within the arc chamber 60.

The number 82 designates an electrode rod preferably consisting of graphite or the like, which is connected to ground or to neutral. The electrode rod 82 extends through the lower face plate 66 and extends axially into the arc chamber 60 to a predetermined degree in order operatively to coact with the graphite plates 78 and to form the arc. Suitable insulation for the electric current is provided, such as the top insulator spacers 84 which are located intermediate the upper face plate 64 and the graphite plates 78. The spacers 84 also function to locate and to maintain the plates 78 in their desired positions in cooperation with the spacers 80. Suitable electrical connections are provided such as the bus bars 87 appearing in Figs. 3 and 4, for energizing the graphite plates 78.

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Fig. 3a shows one form of electrical connection which is suitable for use in conjunction with the apparatus appearing in Figs. 3 and 4, illustrating the ground connection of the electrode rod 82 and the Y-connections for the graphite plates 78.

In the operation of the embodiment of the invention illustrated in Figs. 3, 3a and 4, a fluid medium such as gas or the like is introduced through the inlet 86 in a manner to cool the arc chamber 60 and the cooling chamber 70. The heat of operation preheats the gas in cooling chamber 70 prior to its introduction into the arc chamber 60 through the apertures 72. An arc is struck to the side of the arc chamber and is electrically rotated around the periphery thereof from one graphite plate 78 to the other. In this manner, an arc is produced which creates exceedingly high temperature plasma, which in turn is emitted through the nozzle 76.

The electrode rod 82 is slidable along its axis in order to create and to cut off the arc. The arc can be struck by axially sliding the electrode rod 82 into an arcing position with the graphite plates 78, in response to alternating current input. On the other hand, to disconnect the arc, the electrode rod 82 can be axially removed from the proximity of the graphite plates 78.

Turning now to Figs. 5 and 6, these figures illustrate a preferred form of the invention. The number 90 designates a plenum chamber formed by an inner wall 91 of graphite or the like and an outer cylindrical wall 92 which is preferably made of steel and which is heat-shrunk onto the outside surface of the inner wall 91. The outer wall 92 has spacers 93 near its bottom end, providing a thin air space 94 between the outer wall 92 and a high pressure shell 95. As shown, air space 94 is less than half the thickness of inner wall 91. The number 96 designates an upper wall preferably made of graphite or the like, and the number 100 designates a lower wall preferably made of an insulating material. The upper wall 96 carries a nozzle 101 preferably made of graphite or the like and removably secured to the upper structural flanged member 102 by means of a bolted disc 103.

Means are provided for forming an inlet chamber 104 at the bottom of the apparatus. This means includes a base plate 105 bolted to a flange member 106 which is secured to the high pressure shell 95. Base plate 105 is spaced below the lower wall 100 thereby forming the inlet chamber 104.

Means are provided for introducing and circulating a cooling fluid such as air or gas into and through the apparatus. Such means include an inlet conduit 107 extending through the base plate 105 and into the inlet chamber 104, a plurality of passages 110 which extend through the base plate 100 along an inclined, tangentially-arranged path relative to the center of the arc chamber 90. Each passage 110 comprises essentially a cylindrical bore which is upwardly inclined from the bottom of the lower wall 100 to the top of the lower wall 100, and which is arranged at an angle to the radius and also at an angle to a line perpendicular to the radius as illustrated clearly in Fig. 6. Further openings 111 are provided in the inner and outer walls 91, 92, thereby extending from the narrow air space 94 to the arc chamber 90 for an important purpose which will appear in further detail hereinafter. Means are provided (not shown) for introducing the working fluid such as air or another gas for example into the conduit 107, for flow into the inlet chamber 104, then into the narrow air space 94 and also through the passages 110 into the arc chamber 90. Pressure within the narrow air space 94 is slightly higher than that in the chamber 90 due to the pressure drop of the substantially tangential openings 110, therefore a controlled quantity of such fluid passes through the openings 111 inwardly into the arc chamber 90.

The number 112 designates a blow-out relief pipe having a pressure gauge 113 and having a rupture diaphragm 118. The pipe 112 is connected to a passage 114 extend-

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ing through the base plate 105, such passage being connected to an electrically insulated sleeve 115 which extends through the inlet chamber 104 and the lower wall 100, into the floor of arc chamber 90. A helical spring 116 surrounds the sleeve 115 and the floor 100 rests upon this spring. Similarly, another helical spring 117 is provided, surrounding a pin 120 extending upwardly from an adjusting screw 121. The pin 120 extends into a recess 122 formed in the floor 100, providing freedom of movement of the floor 100 up and down with respect to the base plate 105.

The number 123 designates a plurality of electrodes preferably made of graphite or the like. Each such electrode is supported on a hollow bus bar 124 having an internal baffle 125 and provided with an inlet 126 and an exit 127 for coolant. The bus bar is, accordingly, internally cooled and is also connected to a source of electric power 130. The bus bar 124 extends through an insulated hole in the base plate 105 and has an insulating sleeve 131 extending through the inlet chamber 104.

Novel means are provided for connecting the bus bar 124 to the graphite electrode 123. Extending transversely through a bored hole near the base of the electrode 123 is a pin 132, preferably made of steel or the like. The pin 132 is internally threaded to receive a bolt 133 which is locked in position with respect to the bus bar 124 by a nut and lock washer 134. The graphite electrode is secured in place by simply positioning it at the desired location, inserting the threaded end of bolt 133, and turning the entire bus bar assembly. This tightly screws the end of the bus bar against the end of the electrode 123, providing excellent electrical contact.

From the foregoing description, it will be apparent that the various embodiments of this invention are exceedingly useful for providing plasma material having an exceedingly high temperature, of the order of 5,000° Kelvin and above, which not only provides the temperature and velocity range that is desired for testing purposes, but which also can be regulated in order to provide various desired gaseous compositions. However it will be appreciated that by regulating the rate of flow of the working fluid, temperatures much less than 5000° Kelvin can be obtained, and it is sometimes desired to do this for particular test purposes. For example, quantities of oxygen and other gases may be readily varied.

It will further be apparent that the apparatus in accordance with this invention may be produced in a very substantial size, providing large quantities of exceedingly hot plasma which quantities are necessary for many tests particularly those relating to the missile re-entry problem. The manner in which the gas flow is regulated and constricted provides for constraining the arc in a manner to produce exceedingly high temperatures even when substantial quantities of plasma are being generated. Moreover, the particular manner of constraining the arc in accordance with this invention provides for superior thermal insulation of the strength members, particularly the outer cylinder. While heretofore structures for developing exceedingly high temperature plasma have consumed themselves in very short periods of time such as 1-2 seconds for example, structures in accordance with this invention have been operated successfully for periods of 30 seconds and more.

The rounded construction of the upper ends of the electrodes 123 in Figs. 5 and 6 is an important and advantageous feature of this invention and keeps the arc moving from one point to another such that the temperature does not have an opportunity to accumulate to a destructive level at any one point on the electrode. Although the detailed reasons for this phenomenon are not well known at present, it has been found to be a fact that the rounded construction of the electrodes increases their life and reduces contamination. Apparently it is a peculiar characteristic of high-power arcs

that they move from one location to another quite rapidly and randomly on a curved surface.

As will be seen from Figs. 5 and 6, particularly Fig. 6, each electrode has an outer periphery which is an arc of a circle, together with an inner periphery which is also an arc of a circle which is concentric with the circle just referred to. No sharp edges are provided, and the upper end of each electrode is essentially a portion of a hemisphere. As viewed from the top (see particularly Fig. 6), radii are provided at each point where a sharp change in shape would otherwise appear on the surface of the electrode.

In all of the embodiments of the invention illustrated herein, it is of importance that the graphite liner of the arc chamber is supported by an external liner which is under compression against the graphite liner. Moreover, the provision of a narrow insulating air space just outside the latter contributes further insulation thereby protecting the outer strength member from damage due to excess temperatures.

Although this invention has been disclosed with reference to several specific embodiments thereof, it will be appreciated that various modifications may be made without departing from the scope of the invention. For example, equivalent elements may be substituted for those specifically disclosed and described, parts may be reversed, and certain features of the invention may be used independently of other features all without departing from the spirit or scope of the invention as defined in the appended claims.

It is claimed:

1. An arc plasma generator comprising means forming an arc chamber, such means including an inner wall of heat resistant material and an outer wall maintained under compression against said inner wall, an outer cylinder mounted coaxially with the outer wall of the means forming the arc chamber and radially spaced therefrom to form an annular insulating space outside said outer wall, a plurality of electrodes maintained in said arc chamber, said electrodes being connected to a source of high-power electricity, for forming an electric arc in said chamber, and means for introducing a working fluid into said arc chamber and for causing said working fluid to flow past said electrodes.

2. An arc plasma generator comprising means forming an arc chamber, such means including an inner wall of heat resistant material and an outer wall maintained under compression against said inner wall, an outer cylinder mounted coaxially with the outer wall of the means forming an arc chamber and radially spaced therefrom to form an insulating space outside said outer wall, three electrodes having rounded ends, means for mounting the three electrodes so that they are substantially equidistant from one another and their rounded ends are within the arc chamber, means for connecting said electrodes to a source of three phase electric power to cause the formation of arcs between said electrodes, and means for introducing a working fluid into said arc chamber and for causing said working fluid to flow past said electrodes.

3. An arc plasma generator comprising means forming an arc chamber, such means including a chamber wall of heat resistant material, means forming an insulating air space outside said outer wall, means forming a floor bridging across the bottom of said arc chamber, resilient means for supporting said floor, three electrodes and a ground electrode, means for mounting said three electrodes so that they extend into the arc chamber, means for mounting the ground electrode on said floor, and means for introducing a working fluid into said arc chamber and for causing said working fluid to flow past said electrodes.

4. An arc plasma generator comprising means forming a plenum chamber, such means including an inner wall comprising a plurality of segments of heat resistant

electrical conductor forming electrodes spaced apart from one another by a plurality of non-conductive spacers, and an outer wall maintained under compression against said inner wall, means forming an insulating air space outside said outer wall, and means for introducing working fluid into said arc chamber and for causing said working fluid to flow past said electrodes.

5. In combination, an electrode provided with a transverse bore located near the end thereof, a threadable member loosely disposed in said bore, said member having a threaded bore therein, a conductor adapted for contact with said electrode, and a threaded connecting member secured to said conductor and threaded for engagement within the threaded bore of said member.

6. In combination, a graphite electrode provided with a transverse bore located near the end thereof, a pin loosely disposed in said bore, said pin having a transverse threaded bore therein, a conductor adapted for contact with said graphite electrode, and a threaded connecting member secured rigidly to said conductor and threaded for engagement within the threaded bore of said pin.

7. An arc plasma generator comprising means forming a plenum chamber including a wall of heat resistant material, nozzle means in said chamber for emitting the generated plasma, a graphite electrode in said chamber provided with a transverse bore located near the end thereof, a pin loosely disposed in said bore, said pin having a transverse threaded bore therein, a conductor adapted for contact with said graphite electrode, and a threaded connecting member secured rigidly to said conductor and threaded for engagement within the threaded bore of said pin.

8. An arc plasma generator comprising means forming a plenum chamber, a source of multiphase, high-power alternating current, and a plurality of spaced electrodes in said chamber corresponding in number to the number of phases, each said electrode being composed of a heat resistant material and having a rounded end generally hemispherical in shape.

9. The generator defined in claim 8, wherein each said electrode has a pair of spaced surfaces which comprise substantially concentric arcs of circles.

10. An arc plasma generator comprising means forming a hollow cylindrical arc chamber having a longitudinal axis, said means including an inner wall of heat resistant material, means forming an insulating air space outside said arc chamber, a first rod electrode having a longitudinal axis, means for mounting said first rod electrode so that its longitudinal axis is substantially parallel to the longitudinal axis of the arc chamber and so that a portion extends within the arc chamber, three additional rod electrodes, each of said three additional rod electrodes having a longitudinal axis, means for mounting said three additional rod electrodes so that they extend into the arc chamber through the means forming the arc chamber, so that their longitudinal axes are substantially at right angles to the longitudinal axis of the arc chamber, and so that they are spaced substantially equiangularly with respect to the longitudinal axis of the arc chamber and equidistant from said first rod electrode, circuit means for connecting said first rod electrode to ground, circuit means for connecting said three additional electrodes to a source of three phase alternating current, and means for introducing a working fluid into said arc chamber and causing said working fluid to flow past said electrodes.

11. An arc plasma generator comprising means forming a cylindrical plenum chamber having a longitudinal axis, said means including an inner wall comprised of three substantially equal sized electrodes of a heat resistant electrical conductor, equiangularly spaced around said wall and separated from each other by a heat resistant electrical resistor, a rod electrode mounted for movement within the plenum chamber parallel to the

longitudinal axis of the plenum chamber, circuit means for grounding said movable rod electrode, circuit means for connecting said three segments of heat resistant electrical conductor to a source of three phase A.C. power, and means for introducing a working fluid into said arc chamber and causing said working fluid to flow past said electrodes.

12. An arc plasma generator comprising means forming a plenum chamber, said means including an inner wall having three segments of graphite equiangularly spaced around said wall and separated from each other by a heat resistant electrical resistor, a rod electrode made of graphite mounted so that a part of the rod electrode extends within the plenum chamber, circuit means for grounding said rod electrode, circuit means for connecting said three segments of graphite to a source of three phase A.C. power, and means for introducing a working fluid into said arc chamber and for causing said working fluid to flow past said electrodes.

13. An arc plasma generator comprising means forming an arc chamber; said means including an inner wall of heat resistant material and an outer metal wall heat shrunk onto the outer surface of the inner wall; an outer cylinder of relatively thick metal mounted coaxially with the outer wall of the means forming the arc chamber and radially spaced therefrom to form an annular space; three electrodes; means for mounting said electrodes so that they extend into the arc chamber, so that they are equidistant from one another, and so that they are equidistant from the inner wall of the plenum chamber; each of said electrodes being composed of a heat resistant electrically conductive material and having rounded surfaces; the upper end portion of each electrode being sub-

stantially hemispherical and the inner and outer surfaces of each electrode being portions of concentric cylindrical surfaces; circuit means for connecting each of said electrodes to a source of three phase electrical power; and means for supplying air to the arc chamber, some of said air flowing through the annular space before it flows into the arc chamber to cool the outer cylinder.

14. An arc plasma generator comprising means forming an arc chamber; said means including an inner wall of graphite and an outer metal wall which has been heat shrunk onto the outer surfaces of the inner wall; an outer metal cylinder mounted coaxially with the outer wall of the means forming the arc chamber and radially spaced therefrom to form an annular space; three graphite electrodes mounted in said chamber; each of said electrodes having rounded outer surfaces, the upper end of each electrode being substantially hemispherical in shape, and each of said electrodes having inner and outer substantially concentric cylindrical surfaces; said electrodes being mounted so that they are substantially equidistant from the walls forming the plenum chamber and equidistant from one another; circuit means for connecting each of said electrodes to a three phase source of electrical power; and means for supplying a working fluid to the arc chamber, at least some of the working fluid flowing through the annular space before it flows into the arc chamber to reduce the magnitude of the temperature rise of the outer cylinder.

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