NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: GP

March 27, 1971

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,333,152

Corporate Source : Langley Research Center

Supplementary Corporate Source :

NASA Patent Case No.: XLA-03103

Gayle Parker

Enclosure:
Copy of Patent

NASA-HQ

N71-21693

July 25, 1967 A. P. SABOL 3,333,152
SELF-REPEATING PLASMA GENERATOR HAVING COMMUNICATING
ANNULAR AND LINEAR ARC DISCHARGE PASSAGES
Filed Feb. 24, 1966 3 Sheets-Sheet 1

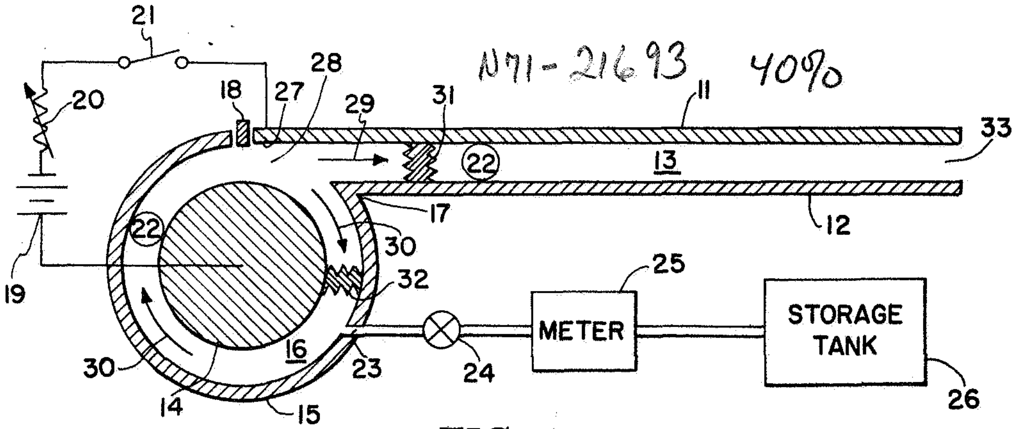

FIG. 1

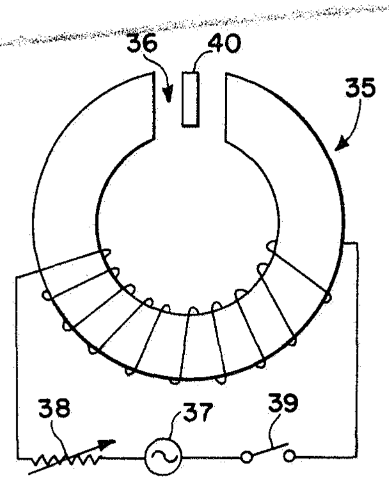

FIG. 2

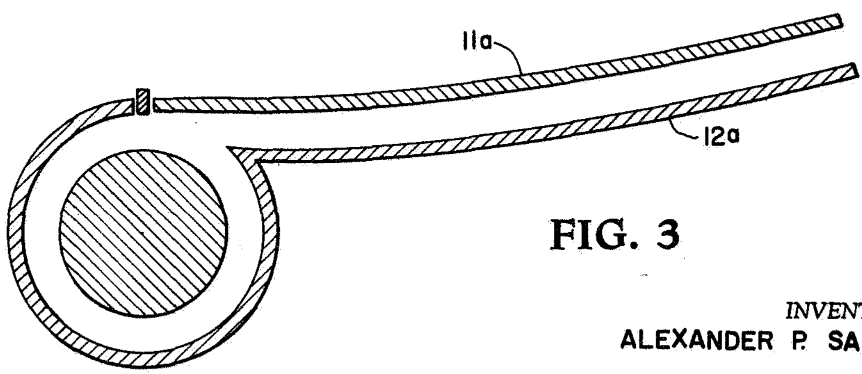

FIG. 3

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SELF-REPEATING PLASMA GENERATOR HAVING COMMUNICATING ANNULAR AND LINEAR ARC DISCHARGE PASSAGES

Filed Feb. 24, 1966 3 Sheets-Sheet 2

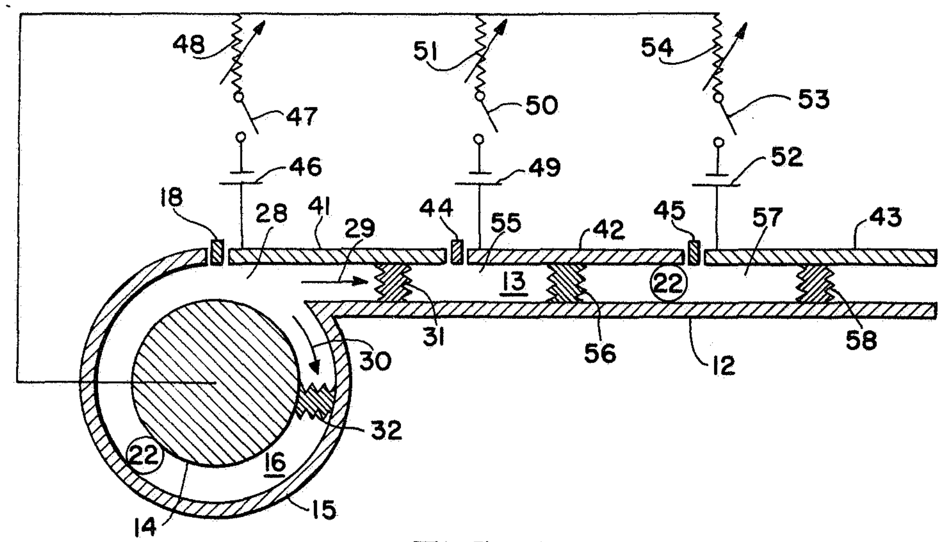

FIG. 4

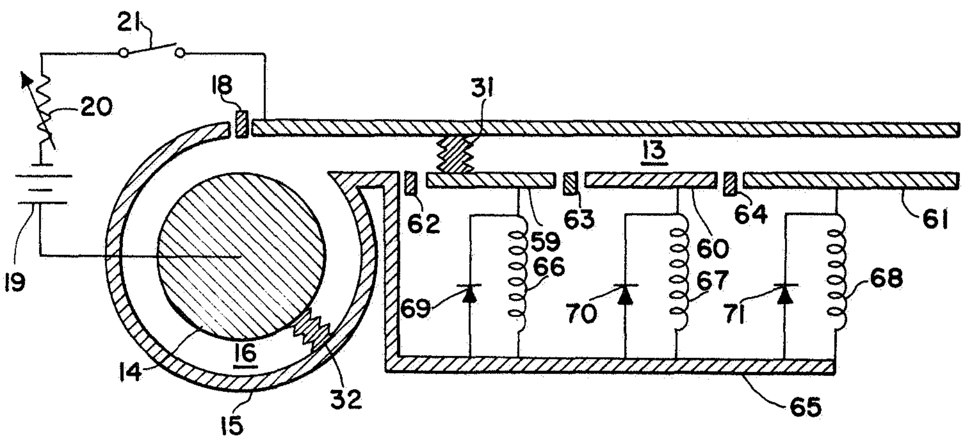

FIG. 5

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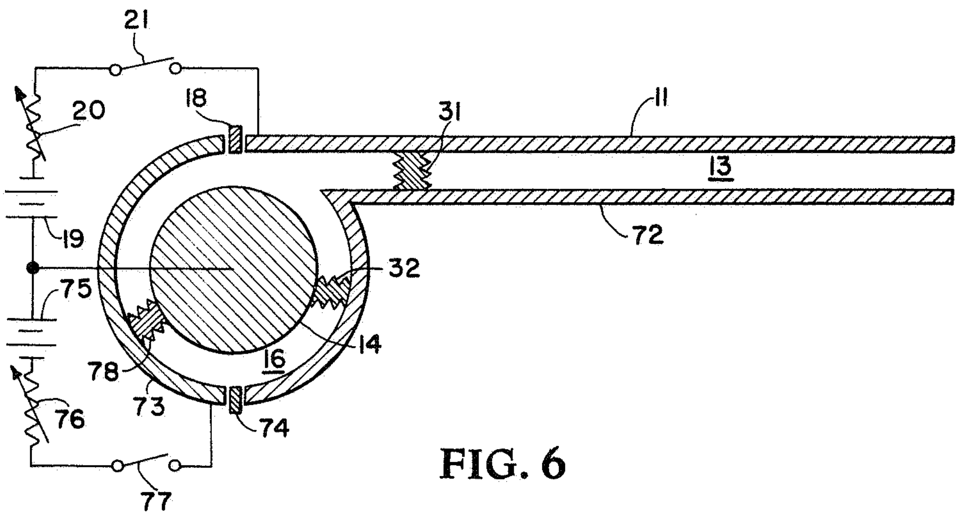

FIG. 6

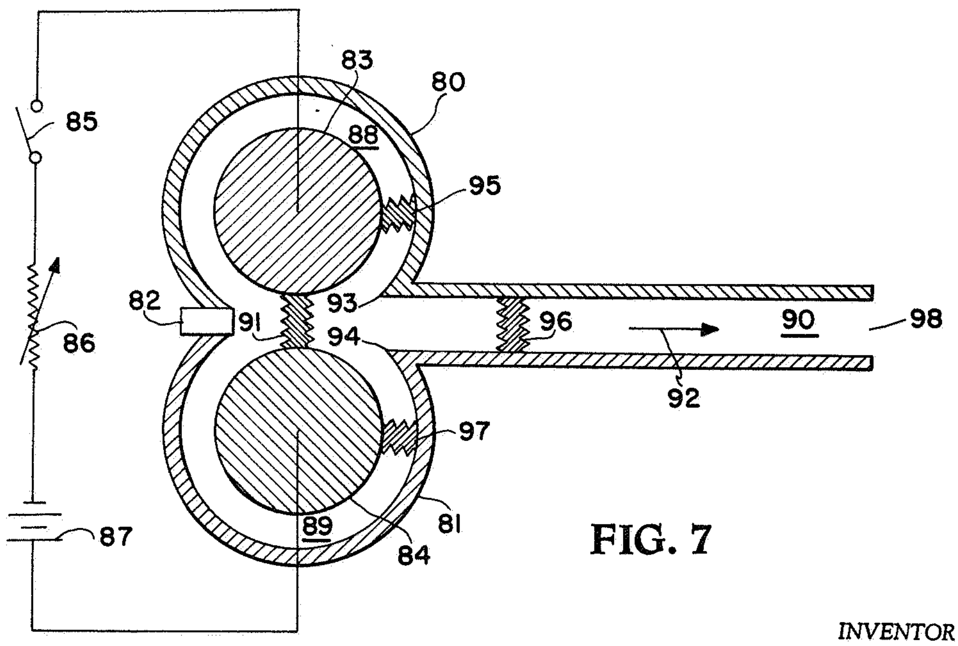

FIG. 7

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3,333,152

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SELF-REPEATING PLASMA GENERATOR HAVING COMMUNICATING ANNULAR AND LINEAR ARC DISCHARGE PASSAGES

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Filed Feb. 24, 1966, Ser. No. 531,642
14 Claims. (Cl. 315—111)

ABSTRACT OF THE DISCLOSURE

A self-repeating plasma generator having an annular channel and a linear channel. The linear channel is tangent to the annular channel and is in communication with the annular channel. Electric fields are created in both channels, a magnetic field is created in both channels perpendicular to the electric fields and to the longitudinal dimension of said linear channel, and a gas is pumped into the channels. When an arc is initiated in the annular channel, it is pulled along the channel until it reaches the linear channel where the arc divides into two arcs. One arc proceeds down the linear channel accelerating the gas in front of it, and the other arc proceeds around the annular channel. Hence, an arc will be initiated and then proceed down the linear channel and accelerate the gas in front of it each time the arc in the annular channel makes a revolution.

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

The invention relates generally to a plasma accelerator and more specifically concerns a direct current powered self-repeating magnetohydrodynamic plasma accelerator.

All plasma accelerators can be divided into two general classes: repetitively pulsed and nonpulsed continuously operated accelerators. The disadvantages of the repetitively pulsed accelerators are that high voltages are required; large electrical capacitors are needed which because of the danger of overheating have a relatively slow operating cycle; timing and switching gear are costly, cumbersome, and may not be reliable for sustained operation; and these components require elaborate engineering design.

There are many types of nonpulsed continuously operated accelerators which have numerous disadvantages. They require exotic cathode materials to provide good emission. "Seeding" materials are used to raise the conductivity of the working plasma which are highly reducing agents, expensive, dangerous, explosive when in contact with water, and require elaborate "seeding" mechanisms that must operate at "red heat" temperatures. In plasma accelerators with segmented electrode arrangements and not using "seeding" materials or using low "seeding" rates, the current paths in the accelerator become confined to narrow areas across the channel causing losses in operating efficiency. Furthermore, these current paths cross the accelerator channel from the leading edge of the cathode to the trailing edge of the cathode to the trailing edge of the anode and then when acted upon by the magnetic field in the channel proper, they are caused to blow downstream and sometimes completely out the end of the accelerator. The attachment of the current path to the trailing edge of the anode produces severe anode erosion that greatly limits the duration of accelerator operation. All electrodes are aligned with edges perpendicular to the direction of flow which is not a good design for producing a smooth wall. Because the attachment points of the current do not move, electrode erosion is most severe due to the currents. As a result of this electrode erosion, the stream becomes contaminated making it unsuitable for aerodynamic testing of boundary layer stability and of heat transfer studies. As the result of electrodes being located perpendicular to the stream flow, uneven erosion rates between electrodes and insulators quickly produce a rough wall which hampers smooth flow. In this type of accelerator a multiplicity of power supplies, switches, and control devices are required making for costly construction and operation. Because of the necessity of supplying power at a variety of voltages to many electrodes, much of the power is lost on control devices. Erosion is enhanced because cathodes are required to operate at high temperatures for best performance. An airstream cannot always be used because of the use of combustible electrodes or "seeding" materials.

It is therefore an object of this invention to provide a plasma accelerator which eliminates many of the disadvantages of prior art plasma accelerators.

Another object of this invention is to provide a self-repeating plasma accelerator which does not require the complicated switching and timing devices usually used in a repetitive type plasma accelerator.

A further object of this invention is to provide a plasma accelerator that can operate in a repetitive fashion when being supplied by only a direct and constant electric current power source.

Other objects and advantages of this invention will further become apparent hereinafter and in the drawings, in which:

FIG. 1 is a cross-sectional view schematic drawing of a preferred embodiment of this invention;

FIG. 2 is a schematic drawing of a device suitable for creating a magnetic field that is required for the operation of this invention;

FIG. 3 is a schematic drawing of a modification of this invention;

FIG. 4 is a schematic drawing of another modification of this invention;

FIG. 5 is a schematic drawing of a further modification of this invention;

FIG. 6 is a schematic drawing of still another modification of this invention; and

FIG. 7 is a schematic drawing of still another modification of this invention.

In describing the embodiments of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

Turning now to the embodiments of the invention selected for illustration in the drawings, the numbers **11** and **12** in FIG. 1 designate two parallel electrodes. This invention has sidewalls (not shown) which are attached to electrodes **11** and **12** to form an enclosed channel **13.** A cylindrical electrode **14** and a concentric electrode **15** together with sidewalls, not shown, form a circular channel **16.** However, as dictated by good aerodynamic practice, the shape of channel **16** may not be precisely circular. It may, for example, resemble a portion of a logarithmic spiral. Adequate seals are used to assure that channels **13** and **16** are leakproof. Electrodes **12** and **15,** which are neutral electrodes and not connected to a power source, are electrically joined together at **17.** Electrodes **11** and **15** are electrically insulated from each other by a refractory type insulator **18.** A power supply **19,** a variable resistor **20,** electrical power monitoring elements (not shown) and a switch **21** are connected in series between electrodes **11** and **14.** The electrical polarity of electrodes **11** and **14** is maintained so as to effect proper operation of the invention. A magnetic field **22** is maintained in channels **13** and **16** perpendicular to the plane of the paper (parallel to the longitudinal dimensions of electrodes **14** and **15**) by any suitable magnetic device such as the one shown in FIG. 2. This magnetic field is a steady field tailored to suit the operating requirements, but is not necessarily uniform over the entire region of channels **13** and **16**. The test gas is introduced through a passageway **23** at any point in channel **16** or channel **13** as may be deemed advisable to the operation. The gas is controlled by a valve **24** and measured by a meter **25**. The gas supply is a storage tank **26** or the atmosphere can be used as the gas supply. This invention can also operate using gases "seeded" with a material of low ionization potential as would be a mixture, say, of helium and lithium or a mixture of nitrogen and cesium. The exhaust end of the accelerator may be open to the atmosphere, outer space, or joined to any suitable apparatus as the mode of operation may require.

In operation the accelerator in FIG. 1 is started in a conventional manner by applying magnetic field **22** to channels **13** and **16**, placing a teaser wire between electrodes **11** and **14** at a point **27** and then closing switch **21** or by any other suitable method. As a result of the difference in potential of electrodes **11** and **14**, an arc discharge is formed in a region **28** which, due to the reaction of the arc current on the imposed magnetic field **22**, travels in the direction of arrow **29**. When the arc reaches point **17** it is pierced by point **17** and attaches to electrodes **12** and **15** to form two arcs **31** and **32** which are pictorially shown. Each of these two arcs travels within the confines of its respective channel **13** or **16** and each experiences an MHD force because of the presence of magnetic field **22**. Because of the proper choice of the length of channel **16** and the magnetic field **22**, when arc **31** reaches region **33** arc **32** simultaneously reaches region **28** where it makes a contact from electrode **14** to electrode **11** at point **27**. This latter action electrically shorts out arc **31** in region **33**. At this moment one cycle of operation is complete and the arc at point **27** is in a position for starting another cycle.

It is seen that the action of the arc in channel **13** is identical to that of a repetitively pulsed accelerator using an external magnetic field. However, it is to be noted that the arc is extinguished the moment it reaches the end of the accelerator at region **33** and not permitted to linger whatsoever in that region. It is also to be noted that the action of arc **32** in channel **16** is identical to existing coaxial arc heaters over the majority of its travel. Thus, as is experienced in other devices, the test gas in channel **13** is caused to move in the direction of arrow **29** by electromagnetic phenomenon existing about the rapidly moving arc **31**. For a similar reason as has been abundantly demonstrated in other devices, the gas in channel **16** assumes a rapid rotation in the direction of arrow **30**. This high velocity gas in channel **16** is caused to enter channel **13** at region **28** where channel **13** tangentially joins to channel **16**. Thus, maximum use is made of the energy expended in channel **16**. It should be noted that the terms "plasma" and "gas" have been used interchangeably in this specification. This is because the working fluid may contain a mixture of both ionized particles and nonionized particles.

Under proper conditions of current, gas flow, pressure and magnetic field this invention assumes a different mode of operation. With these proper conditions arc **32** in channel **16** can be broadened so that it spreads along the length of channel **16**. Any broadening of arc **32** will affect the spread of arc **31** so that broader arcs are fed into both channel **13** and channel **16**. Thus, by this feedback process, arc **32** is broadened until it occupies all of channel **16**. When this happens a diffuse discharge will be established along the entire length of channel **13**, and plasma and propellant will continuously and uniformly accelerate and leave the accelerator in a smooth fashion.

The invention as disclosed in FIG. 1 has been found to operate satisfactorily by placing two identical devices side-by-side so as to form one common channel. Only a thin electrical insulator is needed between the duplicate electrodes. By joining two accelerators this way, more mass flow can be handled and there is a reduction in electrode wear. Also, the invention can be operated by placing two identical devices end-to-end so that the output at region **33** from one accelerator can tangentially enter channel **16** at region **28** of the other accelerator. In addition, since this invention can be operated at different pressures, it can be used as an arc heater by adding to it either a conventional wind tunnel settling chamber and accompanying flow nozzle, or only an aerodynamic expanding nozzle. Both arrangements could employ a conventional evacuating system.

Air or any other gas can be used as the propellant as can a wide range of operating pressures and mass flows of propellant. No special precautions need be taken except those obvious to good engineering practices because the danger of electrical shorts is greatly diminished by the elimination of the plurality of circuits. The propellant or stream can be dumped directly into the atmosphere, an evacuated chamber, or into an external channel designed so as to accelerate or decelerate the flow. Since the accelerator can operate at very high pressures, a nozzle can be placed at the exit to the accelerator which expands the gas streams to a high velocity of a low ambient temperature.

Electrodes **11**, **12**, **14** and **15** are provided for cooling either by a suitable coolant which uses passages provided through the interior of the electrodes or by means of radiation.

FIG. 2 discloses one means for creating the magnetic field **22** in FIG. 1. An electromagnet **35** having an airgap **36** is supplied by a power source **37**. A variable resistor **38** and a switch **39** are provided to control the current in the coil of electromagnet **35**. When a current is passed through the coil a magnetic field is created across airgap **36**. The plasma accelerator in FIG. 1, designated by the number **40** in FIG. 2, is placed in airgap **36**. Consequently, there is a magnetic field in channels **13** and **16** that is parallel to the longitudinal dimension of electrodes **14** and **15**. Obviously, many other magnetic devices could be used to create this magnetic field.

In the operation of this invention, it has been noticed that the stream between the straight electrodes **11** and **12** in FIG. 1 is deflected slightly toward one electrode. In order to compensate for this unwanted deflection, an alternate form of the invention is to replace these straight electrodes with curved electrodes **11*a*** and **12*a*** as shown in FIG. 3. The amount of this curvature depends upon the operating parameters of the invention. The curvature need not be uniform over the entire length of the electrodes and the curvature can be downward instead of upward.

An alternate embodiment of the invention which is shown in FIG. 4 is like the embodiment shown in FIG. 1 except the top electrode is divided into three electrode sections: sections **41**, **42** and **43**. These three electrode sections are separated from each other by insulators **44** and **45**. Electrode section **41** is connected to electrode **14** through a power source **46**, a switch **47** and a variable resistor **48**; electrode section **42** is connected to electrode **14** through a power source **49**, a switch **50** and a variable resistor **51**; and electrode section **43** is connected to electrode **14** through a power source **52**, a switch **53** and a variable resistor **54**. In all other respects, the embodiment in FIG. 4 is exactly like the one in FIG. 1.

In operation of the embodiment in FIG. 4, switches **47**, **50** and **53** are closed and an electrical arc is initiated in region **28** between electrodes **14** and **41** drawing current from power supply **46**. Because of the forces on this arc caused by electromagnetic field 22, the arc moves in the direction of arrow 29 and is divided into two arcs 31 and 32. When arc 31 reaches region 55, arc 32 reaches region 28 where it short circuits arc 31. Arc 32 then proceeds through the same cycle as just explained. In the meantime, the ionized plasma left in region 55 causes power supply 49 to discharge through this plasma to form an arc 56. Upon completion of the second cycle of operation for arc 32, arcs 31 and 56 will have reached regions 55 and 57, respectively. Then as arc 32 shorts between electrodes 14 and 41 in region 28, arcs 31 and 56 are extinguished. This instant is the beginning of the third cycle for arc 32 which then divides into two arcs again. Because of the plasma in regions 55 and 57, and the power sources 49 and 52 across these regions, arcs 56 and 58 are initiated.

By proper design and operation, as arc 32 rotates in the direction of arrow 30, all three arcs 31, 56 and 58 move in the direction of arrow 29. When arc 32 nears the vicinity of region 28, each arc 31, 56 and 58 approaches the trailing end of electrodes 41, 42 and 43, respectively. Thus, when arc 32 shorts between electrodes 14 and 41, arcs 31, 56 and 58 are extinguished simultaneously.

All the current supplied by each power supply 46, 49 and 52 passes through arc 32. The voltage drop in arc 32 is determined by the particular values of parameters selected for channel 16, which are smaller than those in channel 13 in order to minimize losses. Because of the differences in the velocities of arcs 31, 56 and 58 the potentials of the three power supplies are different. It is to be noted that in the case illustrated, four electrical arcs exist simultaneously during each cycle.

The embodiment of the invention shown in FIG. 4 can be modified by connecting the upper ends of variable resistors 51 and 54 to electrode 12 instead of to electrode 14. In this manner more electrodes similar to electrodes 42 and 43 can be added since with this arrangement the current from all power supplies does not have to pass through arc 32.

Another alternate embodiment of the invention which is shown in FIG. 5 is like the embodiment shown in FIG. 1 except the bottom straight electrode is divided into three electrode sections: electrode sections 59, 60 and 61. These three electrode sections are separated from each other and from electrode 15 by insulators 62, 63, and 64. A bus bar 65 is attached to electrode 15. Coils 66, 67 and 68 are connected between bus bar 65 and electrodes 59, 60 and 61, respectively. Diodes 69, 70 and 71 are connected in parallel with coils 66, 67 and 68, respectively. There is a magnetic field in channel 16 perpendicular to the plane of the paper; however, there is not necessarily a magnetic field in channel 13. The necessary magnetic field in channel 13 is supplied by coils 66, 67 and 68. In all other respects the embodiment of the invention in FIG. 5 is like that in FIG. 1. The operation of the embodiment in FIG. 5 is like that in FIG. 1 except that arc 31 is pulled along channel 13 by the magnetic fields created by the current through coils 66, 67 and 68.

FIG. 6 shows a further embodiment of this invention. The only differences between this embodiment and the one in FIG. 1 are that electrode 12 is divided into two electrodes 72 and 73 that are separated by an insulator 74, and electrode 73 is connected to electrode 14 through a power source 75, a variable resistor 76 and a switch 77. In all other respects the two embodiments are the same. In the operation of this device two arcs 32 and 78 are formed in channel 16 instead of one. Any number of electrodes similar to electrode 73 could be added to this embodiment.

In a still further embodiment of this invention shown in FIG. 7, two electrodes 80 and 81 are separated by an insulator 82. An electrode 83 is located inside electrode 80 and concentric therewith, and an electrode 84 is located inside electrode 81 and concentric therewith. Electrodes 83 and 84 are connected together through a switch 85, a variable resistor 86, and a power source 87. A magnetic field, not shown, is created in channels 88, 89 and 90 perpendicular to the plane of the paper.

The operation of this embodiment is similar to the operation of the embodiment in FIG. 1. An arc 91 is initiated by conventional means between electrodes 83 and 84. Because of the Lorentz force present, arc 91 moves in the direction of arrow 92. Points 93 and 94 pierce arc 92 to form arcs 95, 96 and 97. Arcs 95 and 97 continue in their motion as does arc 96 until arcs 95 and 97 collide with each other at insulator 82 to form a single arc which moves into the position of the previous arc 91. Meanwhile, arc 96 has been extinguished at point 98 by the formation of the arc across insulator 82 which shorts the electrical conducting path through electrodes 80 and 81. Arc 91 now follows the same sequence of events as described to form a new arc 96 in channel 90. The motion of arc 91 causes the working gas to move in channel 90 in the direction of arrow 92 to point 98 where the resulting high velocity gas is used for a desired purpose.

The advantages of this invention are numerous. It can be operated with air. It can be operated over a wide range of pressures. It can be used in conjunction with an aerodynamic nozzle to produce a high velocity stream of a low ambient temperature. No exotic metals need be used as electrodes. The power supply is a direct and constant current source requiring no additional mechanisms to create a repetitive pulse. The repetitive action is automatic and is maintained by the accelerator itself and it is of a high frequency. The unit has no electrodes placed perpendicular to the stream flow to create a rough wall because of uneven erosion rates between electrode and insulator. The discharge arc is automatically extinguished when it reaches the electrode end and does not hang there to cause severe erosion. Because of the swift movement of the discharge arc, erosion of the electrodes is negligible causing low stream contamination. Thus, many aerodynamic and heat transfer studies can be made in an atmosphere. Because of the use of common or corrosion resistance metals, many types of gases can be used. The discharge arc does not balloon out the end of the channel but is promptly extinguished when it reaches the channel end. The energy that is expended in region 14, FIG. 1, sets the gas in motion and this motion is completely utilized in the pulse region of the accelerator, thus, losses are minimized. The entire setup embodies simplicity of design, construction, and operation. Loss of power in control devices is negligible.

It is to be understood that the forms of the invention herewith shown and described are to be taken as preferred embodiments. Various changes may be made in the shape, size and arrangement of parts. For example, equivalent elements may be substituted for those illustrated and described herein, parts may be reversed, and certain features of the invention may be utilized independently of the use of other features, all without departing from the spirit or scope of the invention as defined in the following claims.

What is claimed is:

1. A self-repeating plasma accelerator comprising: an annular first channel; a second channel that is straight with one of its ends open and with its other end connected in communication with said first channel such that a sharp edge is formed between said first and second channels where they meet; means for creating an electric field in said first and second channels capable of sustaining arcs in said first and second channels; means for creating a magnetic field in said first and second channels perpendicular to said electric field and perpendicular to the longitudinal dimension of said second channel for moving arcs in said first and second channels along their respective channels; and means for injecting a gas into said first channel whereby when an arc is initiated in said first channel it moves along said first channel until it

reaches said sharp edge which divides it into two arcs one of which moves along the second channel and the other of which moves along the first channel thereby creating repeating arcs in the second channel which accelerate said gas out the open end of said second channel.

2. A self-repeating plasma accelerator according to claim 1 wherein said second channel is curved along its longitudinal axis.

3. A self-repeating plasma accelerator according to claim 1 wherein a third channel like said first channel is tangentially connected to said first channel whereby arcs are formed in both said first and third channels which combine where said first and third channels are connected together and said combined arc divides into an arc for each of the three channels.

4. A self-repeating plasma accelerator comprising: a first curved electrode; a second curved electrode spaced from, interior to, and concentric with said first electrode to form a continuous first channel; a straight third electrode; a straight fourth electrode spaced from said third electrode to form a second channel, the third and fourth electrodes being located relative to said first and second electrodes so that said second channel is connected in communication with said first channel; means forming a sharp edge between said first and fourth electrodes and electrically connecting said first and fourth electrodes together; a power source connected between said second and third electrodes for creating electric fields between said first and second electrodes and between said third and fourth electrodes capable of sustaining arcs in said first and second channels; means for injecting a gas into said first channel; and means for creating a magnetic field in said first and second channels perpendicular to said electric field and to the longitudinal dimension of said third and fourth electrodes for moving arcs in said first and second channels along their respective channels whereby when an arc is initiated between said second and third electrodes it moves in said first channel until it reaches said sharp edge which divides it into two arcs the first of which proceeds along said first channel and the second of which proceeds along said second channel to accelerate the gas in front of it and out of the open end of the second channel, the first arc proceeds along the first channel until it terminates the arc at the end of the second channel and forms another arc between said second and third electrodes.

5. A self-repeating plasma accelerator according to claim 4 wherein said third electrode is divided into several sections with each insulated from the other and with a different power source connected between each section and said second electrode.

6. A self-repeating plasma accelerator according to claim 4 wherein said first curved electrode is divided into two sections that are insulated from each other with a second power source connected between one of the sections and said second electrode whereby two arcs are maintained in said first channel at all times.

7. A self-repeating plasma accelerator according to claim 4 wherein said fourth electrode is divided into several sections that are insulated from each other with a different magnetic coil connected between each section and said second electrode whereby the current through said coils create magnetic fields which pull said second arc along said second channel.

8. A self-repeating plasma accelerator comprising: a hollow cylindrical first electrode; a second cylindrical electrode spaced from, interior to, and concentric with said first electrode to form an annular first channel; an opening in the wall of said first electrode; a straight third electrode tangent to said first electrode at said opening and insulated from said first electrode; a straight fourth electrode connected to said first electrode at said opening and tangent to said second electrode to form a sharp edge between said first and fourth electrodes wherein a straight second channel is formed that is open at one end and that is connected at its other end to said first channel at said opening and wherein said sharp edge will divide any arc moving around said annular channel into two arcs; means for creating electric fields in said first and second channels capable of sustaining arcs in said first and second channels; means for producing a magnetic field in said first and second channels that is parallel to the longitudinal dimension of said first and second electrodes for moving arcs in said first and second channels along their respective channels; and means for injecting a gas into said first channel whereby when an arc is initiated in said first channel the arc moves in said first channel until it comes to said sharp edge which divides it into two arcs one of which moves in said second channel toward said open end pushing gas in front of it and the other of which moves around said second channel to said sharp edge where another cycle is started.

9. A self-repeating plasma accelerator according to claim 8 wherein the circumference of said first channel is approximately equal to the length of said second channel whereby it takes the same time for an arc to travel the length of said second channel as it does for an arc to travel the circumference of said first channel.

10. A self-repeating plasma accelerator according to claim 8 wherein said first electrode is divided into two sections with the electric field between one section and said second electrode being different from the electric field between said second and third electrodes.

11. A self-repeating plasma accelerator according to claim 8 wherein said fourth electrode is divided into several sections that are insulated from each other and from said first electrode and a different magnetic coil is connected from each section to said first electrode to provide a changing magnetic field in said second channel.

12. A self-repeating plasma accelerator according to claim 8 wherein said third and fourth electrodes are curved.

13. A self-repeating plasma accelerator according to claim 8 wherein said third electrode is divided into several sections with each insulated from the other.

14. A self-repeating plasma accelerator according to claim 13 wherein the electric fields between said sections and said third electrode are different.

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