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

REPLY TO
ATTN OF:

N70-36946

July 21, 1970

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. : 3,174,278

Corporate Source : Nat'l Aeronautics & Space Admin.

Supplementary
Corporate Source : Langley Research Center

NASA Patent Case No.: XLA-01354

Gayle Parker

Enclosure:
Copy of Patent

N70-36946

CONTINUCUSLY OPERATING INDUCTION PLASMA ACCELERATOR

Filed Jan. 24, 1963 2 Sheets-Sheet 1

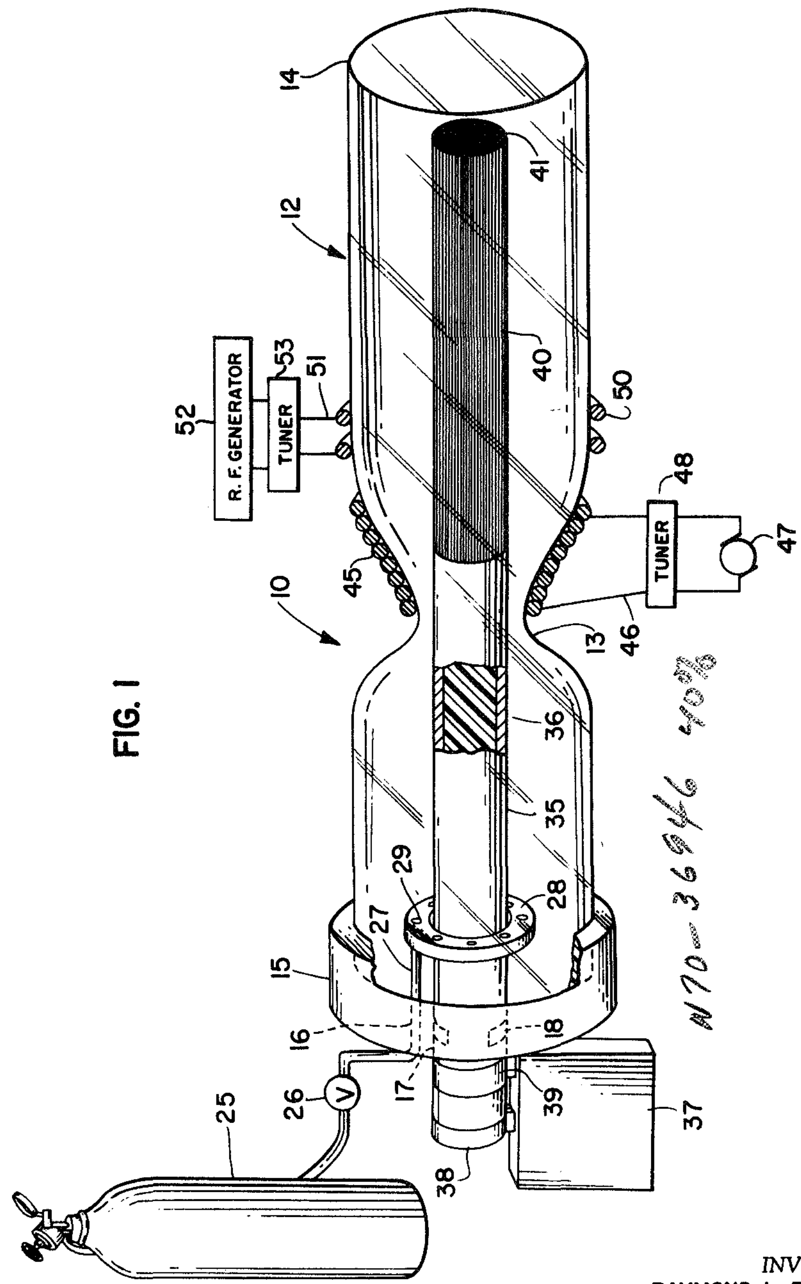


FIG. 1

INVENTORS
RAYMOND L. BARGER
JOSEPH D. BROOKS
WILLIAM D. BEASLEY

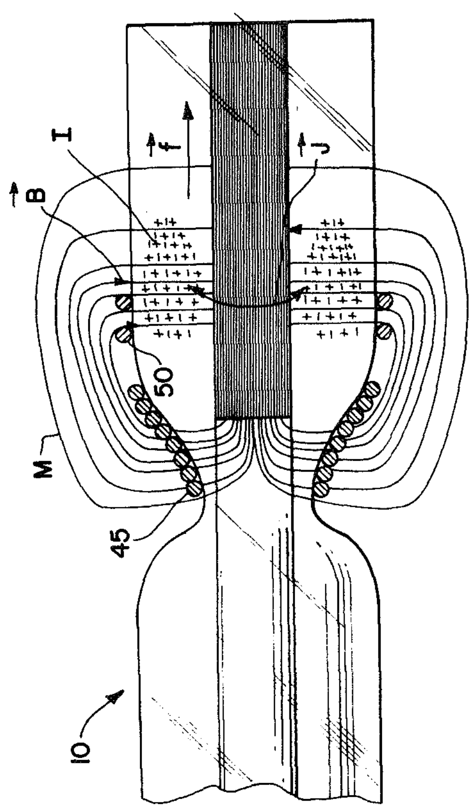
BY G. D. O'Brien
Howard J. Osborn
ATTORNEYS

March 23, 1965 R. L. BARGER ETAL **3,174,278**

CONTINUOUSLY OPERATING INDUCTION PLASMA ACCELERATOR

Filed Jan. 24, 1963 2 Sheets-Sheet 2

FIG. 3



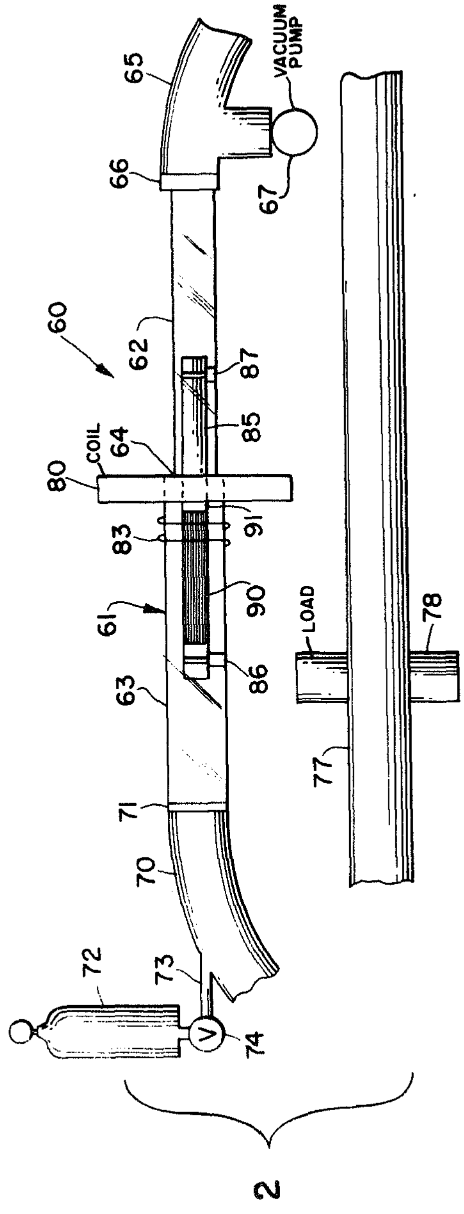


FIG. 2

INVENTORS
RAYMOND L. BARGER
JOSEPH D. BROOKS
WILLIAM D. BEASLEY

BY G. D. O'Brien
Howard J. Osborn
ATTORNEYS

United States Patent Office

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3,174,278

CONTINUOUSLY OPERATING INDUCTION PLASMA ACCELERATOR

Raymond L. Barger and Joseph D. Brooks, Newport News, and William D. Beasley, Hampton, Va., assignors to the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

Filed Jan. 24, 1963, Ser. No. 253,774

23 Claims. (Cl. 60—35.5)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to a device for motivating an ionizable material, and more particularly to an induction type plasma accelerator.

Various devices have been proposed for driving gases to a high velocity, these devices often being termed plasma accelerators. One such accelerator utilizes electrodes, electron emission at the cathode being attracted to the anode the resulting current interacting with a magnetic field to accelerate ionized gas. Although this device functions as an accelerator, it has the disadvantage of electrode erosion because of the high temperatures required for electron emission at the cathode and because of the heat generated by deionization at the anode. The erosion results in a gradual depletion of the electrode so that they must be replaced periodically. Thus, this type of accelerator could not be utilized, for example, as a low-thrust electric propulsion unit on a long space flight. Also, electrode erosion would be a problem if the accelerator were used as a stage of a testing device, this being true because the metal vapor being introduced into the flow from the electrodes would condense on the test model and in general interfere with the highly controlled conditions that are necessary for accurate testing.

Another type of plasma accelerator embodies the principle of acceleration by longitudinal electrostatic field gradient. Although this system is workable to a degree, it has the disadvantage that it is limited in its application to plasmas in which the electron density is so low that the Debye shielding distance is sufficiently long for the required field gradient to be maintained and to be effective. Due to this limitation, acceleration by longitudinal electrostatic field gradient would have limited applicability for use, for example, as a low-thrust electric propulsion unit.

Accelerators have been proposed which use the induction principle, but have been based on the traveling magnetic field concept requiring a phased sequence of coils. This system is extremely hard to work due to the difficulty in controlling the sequential operation of the coils such that acceleration of the plasma is accomplished. It is also difficult to obtain continuous operation of the coil due to the deionization of the gas at various points as the coils are operated sequentially.

The present invention overcomes the many difficulties inherent in the above discussed accelerators. Since the present invention utilizes an induction principle, there is no problem with electrode erosion or decay. Furthermore, there is no discharge of metallic vapor into the plasma, since there are no metal elements exposed to the gaseous medium. The Debye shielding distance is of no concern when using the induction principle, gases of high electron density may be utilized, and generally speaking are desirable. The invention here under consideration is a continuously operating plasma accelerator using only one driver coil, which is single phased. Thus, an extensive region of highly ionized plasma is not required as

with the traveling field concept wherein several coils are utilized and phased sequentially. This is true, because the highly conductive plasma is localized within the vicinity of the ionization driver coil. Obviously the power supply and electrcal circuitry for the invention are much simpler than that for a poly-phased system required for the travelling magnetic field device. Furthermore, the circuit in the present invention can be tuned more easily than a poly-phased circuit.

It is, therefore, an object of this invention to provide a plasma accelerator, using a continuously operating induction principle capable of producing supersonic speeds.

Another object of this invention is to provide a plasma accelerator wherein a source of high frequency is utilized to maintain a portion of the gas within the accelerator ionized.

Yet another object of this invention is to provide a plasma accelerator wherein the magnetic lines linking the ionized gas are directed radially, thereby interacting with the current induced in the ionized gas to provide a force in the direction of plasma flow.

A further object of the invention is to provide a plasma accelerator which utilizes a single-phased induction system.

Yet another object of the invention is to provide a plasma accelerator which utilizes an auxiliary ionization coil to maintain an ionized loop in the plasma so that it wll not become nonconductive between the peaks of current induced by the main driver coil.

Still another object of this invention is to provide a plasma accelerator which utilizes a highly permeable material within the accelerator to increase magnetic lines of flux, thereby increasing the voltage induced in the gas and the degree of ionization.

A further object of the invention is to provide a plasma accelerator utilizing a material having a high degree of permeability therein whereby the current loop induced in the ionized gas is located close to the inducing means, but downstream from it to prevent a braking action on the plasma flow.

Still another object of the invention is to provide a device for motivating an ionizable material, the principle of which can be utilized to accelerate a plasma, operate as a low-thrust plasma engine and be utilized to pump an ionizable gas.

Yet another object of the invention is to provide a plasma accelerator which will produce velocities of supersonic speeds.

Another object of the invention is to provide a plasma accelerator which is of simple design, economical to manufacture and maintain, is re-startable and operative over a long time interval.

Still another object of this invention is to provide a plasma accelerator which is operable over a wide pressure range.

These and other objects and advantages of the invention will become more apparent upon reading the specification in conjunction with the accompanying drawings:

In the drawings:

FIGURE 1 is a perspective view, partially cut away, showing a plasma accelerator in the form of a plasma propulsion engine;

FIGURE 2 is a cross sectional view showing a plasma accelerator utilized as a pump;

FIGURE 3 is a cross sectional view of the plasma accelerator showing diagrammatically the inner action of the electric and mangetic lines of force to provide a force in the direction of flow.

Basically, this invention relates to a plasma accelerator which utilizes a continuously operating induction principle to accelerate a plasma. The accelerator has a flow chamber including a nozzle. An ionizable gas is introduced into the flow chamber upstream of the chamber nozzle. A ring of ionized gas is maintained downstream of the nozzle by a high frequency (radio-frequency) coil which surrounds the flow chamber. An induction or driver coil surrounds the nozzle of the flow chamber and provides a source of high power for greatly increasing the ionized state of the gas. The ionized gas operates as a secondary coil whereby a current is induced therein by the primary. Since the current induced in the ionized ring is always in a direction so as to oppose the current in the driver coil, the charged particles carrying the current are driven downstream and exert an accelerating force on the neutral gas particles by their collisions with them. An iron core is mounted in the flow chamber in a manner such that it extends downstream through the ionized gas ring originating within the driver coil. The iron core has the effect of causing the magnetic lines linking the current ring induced in the ionized gas to be radially directed. This is an ideal situation since the induced current direction is circumferential, the magnetic lines should be in a radial direction so that the resultant force on the plasma will be in a longitudinal direction or the direction of plasma flow.

Referring now more specifically to the details of the invention, FIG. 1 illustrates a plasma accelerating assembly designated generally by the reference numeral **10**. The assembly **10** is in the configuration of a low-thrust electric propulsion unit or plasma engine.

The plasma engine **10** includes a thrust chamber **12** constructed of a nonconducting material. For purposes of testing the thrust chamber was made of Pyrex; however, for space application the chamber could be constructed from boron nitride, Vycor or some other nonconducting material which is nonporous and has the necessary strength properties. The thrust chamber **12** has a contoured nozzle **13**. The thrust chamber **12** has an open end **14** through which the plasma is exhausted. The other end of the thrust chamber **12** is closed by head or cap **15**. It should be understand, that the end of the thrust chamber **12** may be closed by material formed integral with the chamber. Means is provided between the chamber **12** and the cap **15**, such as an O-ring seal, to render the chamber pressure tight or vacuum tight. The head **15** has a gas inlet **16** and a casing passage **17**. These openings are provided with appropriate seals (not shown) whereby the chamber is rendered pressure tight or vacuum tight.

As gas container **25** is connected by a gas line **27** with a manifold **28** located within the thrust chamber **12**. The gas line **27** passes through the chamber head **15** via the gas inlet **16**. A valve **26** is located in the gas line **27**, and is utilized to control the rate of flow into the thrust chamber. The manifold **28** is a ringlike member having a series of apertures **29** dispersed circumferentially about its downstream face so as to introduce a uniform gas flow into the thrust chamber. The gas utilized must be of an ionizable nature, the gas argon having been successfully used. It is to be understood; however, that other readily ionized gas may be utilized. The gas is normally stored in a conventional pressurized container or containers.

A tubular casing **35** is centrally located within the thrust chamber **12** and extends from the open end **14** through the casing passage **17** and beyond the chamber head **15**. The casing **35** is made of a dielectric material such as Pyrex and contains a casing beam **36** which is also made of a dielectric material such as Micarta. The beam **36** extends from the upstream edge of the iron core and through the chamber cap **15** to the end of the casing **35**. A pair of casing clamps **38** and **39** surround the casing **35** and are fixed to the support **37**. The support **37** is shown as a block for purposes of illustration; however, in actual application of the support it could be part of the satellite or spacecraft frame or other available structure. From the above description, it is clear that the casing **35** is supported in a cantilever fashion. The purpose of this is to reduce interference with the flow of plasma through the thrust chamber. The beam lends structural support to the casing **35** such that the cantilever mounting of the casing is made possible. Another reason for the ringlike manifold **28** is now also apparent, since it is necessary that the manifold surround the casing **35**.

The casing **35** also supports the iron core **40**. The iron core **40** is constructed of a number of closely packed wires or laminated strips **41**. These wires or strips may have a dimension in the neighborhood of ½ millimeter, this particular structure of the iron core being utilized to reduce eddy currents and thereby increase the efficiency of operation. The iron core **40** extends from the open end of the thrust chamber **12** to a position adjacent the nozzle **13**. The iron core **40** also abuts the end of the beam **36**. The purpose for this is to prevent the iron core from being drawn through the induction coil or driver coil now to be described.

The driver coil **45** is of a conventional design, and is wound along the nozzle **13** of the thrust chamber as shown in FIG. 1. The driver coil **45** is connected by power lines **46** through a tuning circuit **48** to a motor generator **47**, shown diagrammatically. During tests a motor generator operating at 10 kilocycles with an output of 36-kilowatts was found well suited to the operation of the accelerator; however this requirement may be varied as the situation demands.

A high frequency coil of conventional design surrounds the thrust chamber **12** downstream of the nozzle **13** and is spaced from the driver coil **45**. The high frequency coil **50** is connected by lines **51** to an oscillator or transmitter **52**, illustrated diagrammatically, operable in the radio-frequency range. The radio-frequency generator **52** is associated with a tuning circuit **53**, illustrated diagrammatically, which is utilized to tune or obtain the optimum frequency for ionizing the gas within the thrust chamber.

FIGURE 2 shows an alternate embodiment of the invention whereby the accelerator is utilized as a pump, designated generally by the reference numeral **60**. The pump **60** has a chamber **61** which is of a stepped configuration, having a constricted portion **62** and an expanded portion **63**. The chamber size differential forms a nozzle **64**. The chamber **61** is made of a dielectric material similar to that of the accelerator thrust chamber **12**.

An inlet duct **65** is secured to the chamber **61** in a conventional manner and is sealed by a commercially available seal **66**, shown diagrammatically. Associated with the duct **65** is a vacuum pump **67**. Since it is very difficult to prevent a certain amount of leakage in a closed pumping system, the vacuum pump **67** is utilized to maintain the desired pressure within the pump.

An outlet duct **70** is connected to the opposite end of the chamber **63** and has a seal **71** also shown diagrammatically. As gas supply or container **72** communicates with the outlet duct **70** via the pipe **73**. A control valve **74** is located in the line **73** and regulates the flow of ionizable gas into the outlet duct **70**.

A portion of the return conduit **77** is shown in FIG. 2, and a load **78** (shown diagrammatically) is associated with the return conduit. Portions of the duct work are cut away; however, it is to be understood that the duct work is designed such as to give optimum flow of the plasma from the outlet duct to the load **78** and back to the inlet duct **65**.

Surrounding the nozzle **64** of the chamber **61** is a driver or induction coil **80**. The driver coil is of a design similar to that of the driver coil **45**, and is supplied with a similar power source; therefore, will not again be explained in detail. Likewise, the radio-frequency coil **83** is similar in design to the high frequency coil (radio-frequency coil

50) discussed above. The high frequency coil 83 is spaced from the driver coil 80, and is located downstream thereof.

A casing 85 made of dielectric material is centrally located within the chamber 61. It is constructed from a dielectric material, and is supported on its respective ends by platforms 86 and 87. The platforms 86 and 87 are designed so as to interfere as little as possible with the plasma flow. Forming a part of the platforms 86 and 87 are clamps which surround the casing and are securred to the platforms.

Supported within the casing 85 is an iron core 90, of a laminated nature or formed from a series of wires to reduce eddy currents. It extends through the high frequency coil 83 to a position adjacent the driver coil 80. A plug 91 abuts the end of the iron core 90 to prevent it from being drawn through the driver coil 80. The iron core 90 extends in the other direction throughout a major portion of the casing 85.

Operation

The principle of operation of the mechanism is similar whether the device is used as an accelerator, a plasma propulsion engine or a pump. However, for purposes of illustration, the operation of the mechanism shown in FIG. 1 will be described.

Initially, the gas from the container 25 is admitted into the thrust chamber 12. The valve 26 regulates the flow of gas into the thrust chamber 12, a continuous supply of gas being needed if the device operates as a plasma propulsion engine since the charged particles are exhausted into the space environment. It has been found that the device will operate at a gas discharge pressure from the manifold 28 in the range of one tenth millimeter mercury to one hundred millimeters mercury. As shown in FIG. 1, the gas in introduced into the thrust chamber in a uniform pattern by the manifold 28 which forms a ring and has apertures which are evenly dispersed about the ring. The valve 26 may be solenoid operated, the solenoid being remotely controlled with the devices in a space environment.

The high frequency coil 50 is then activated. In tests it has been found that the radio-frequency oscillator 52 operating at a frequency of 30-megacycles with an output of 1,200 watts would deliver a power to the gas of approximately 1,000 watts. This is sufficient to produce an ionization ring I, illustrated diagrammatically in FIG. 3. The ionization ring I is composed of a number of charged particles represented by plus and minus signs, as well as neutral particles (not shown) dispersed throughout the charged particles. The coil 50 is tuned to provide optimum ionization of the gas. In tests the tuning is done visually by observing the glow intensity of the gas. From experiment the optimum frequency can be determined to permanently tune the coil 50 if used in a space environment. The driver coil is then energized. The driver coil in test operated at a frequency of 10 kilocycles and was powered by a motor generator which had an output of approximately 36 kilowatts at a maximum voltage of 440 volts. The output of the driver coil, of course, can be varied as required. The magnetic field M (FIG. 3) produced by the driver coil 45, induces large currents in the ionization ring I. The ionization ring I, is in principle the same as a single turn wire secondary. The power induced into the ionization ring I by the driver coil greatly accelerates the charged particles. Since the current induced in the ionization ring I is always in such a direction as to oppose the current in the driver coil, the charged particles carrying the induced current are driven downstream and exerts an accelerating force on the neutral gas particles by their collision with them.

The driver coil surrounds the nozzle of the flow chamber to provide a good magnetic coupling between the driver coil and the plasma. The flow chamber is, therefore, designed to have a smoothly contoured constriction, a step change in diameter or some other design. The constriction in the flow chamber provides a certain amount of acceleration according to the well known Venturi principle.

This operation is aided by the iron core which is located within the thrust chamber. As is shown in FIG. 3 the iron core projects through and is surrounded by the ionization ring I, and terminates adjacent the driver coil. The iron core may extend a small distance into the windings of the driver coil but should not extend farther than the first few turns, for purposes which will be explained more fully hereinafter. The presence of the iron core increases the magnetic flux density M, thereby increasing the voltage induced into the gas. The iron core further has the effect of causing the magnetic lines linking the current ring formed in the ionization ring I to be radially directed. This is illustrated by the vector arrow B in FIG. 3. Since the current in the ionization ring I is circumferential, the magnetic lines should be in the radial direction so that the resultant force on the plasma or ionized gas will be in the longitudinal or flow direction. Thus, the vector equation $F=J\times B$ may be written, F representing the resultant force on the plasma, B the radially directed magnetic lines and J the current within the ionization ring I.

The current induced in the ionization ring I by the driver coil should be situated close to the driver coil but downstream from it. Since the driver coil current and the induced current oppose each other, any current induced upstream of the driver coil would have a braking action on the flow, and current induced directly within the driver coil would not produce a force in the discharge direction. The location of the ionization ring, and thus the induced current therein, is accomplished partly by the radio-frequency ionization coil, but is also controlled by the positioning of the iron core in such a way that the iron extends through the radio-frequency coil but not completely through the driver coil. Thus, the importance of properly locating the iron core within the thrust chamber is explained. The voltage induced by the driver coil in the ionization ring (within the area of the radio-frequency coil) is then larger by a factor of two or three than the voltage induced directly inside the driver coil upstream of the core. It is important to maintain the voltage within the ionization ring I as high as possible, as well as inducing a larger current in the ionization ring, since it is a principle of a partially ionized gas that the more ionization that takes place, the more susceptable the gas is to ionization. Thus, the gas does not become saturated as the secondary of the transformer might. By increasing the induced voltage the total coupled into the plasma is increased.

The high frequency (radio-frequency) coil performs another important function in the operation of the device. Since an induction principle is being utilized, an alternating current is necessary for induction to take place. It is well known that the output from an alternating current generator represents a cycling current and voltage. Thus, the current and voltage cycle through zero to a maximum peak, through zero to a minimum, through zero and so on. When the current is zero on any given cycle, the induction into the ionization ring I is also essentially zero. It, therefore, becomes apparent if only the driver coil 45 were utilized it is possible that as the current is at zero the gas within the chamber can deionize and thereby require a considerable induced voltage to reionize the gas resulting in a substantial loss in efficiency of operation and/or intermittent sporadic type operation. However, with the utilization of the high frequency (radio-frequency) ionization coil, there is maintained an ionization ring I. Thus, as the current starts to build up in any particular cycle, the current induced is immediately applied to the already ionized particles, the power of the inducing current thus being utilized to its fullest extent to accelerate rather than to produce initial ionization. Also, any chance of sporadic operation is eliminated since this is a continuous ring of ionized gas maintained by the ionization coil.

The mode of operation of the pump **60**, shown in FIG. 2, is similar to that of the accelerator or plasma engine **10**. The supply of an ionizable gas to the closed circuit pump is somewhat different in that it is not necessary to continuously supply the chamber **62** with gas. This is true, since the gas within the chamber is ionized, forced through the outlet duct **70** to the load **78** and returned through the inlet duct and again ionized. However, due to the difficulty in preventing escape of a certain amount of gas in a closed circuit system, a controlled leak from the gas supply **72** may be desirable. This leak may be regulated by the valve **74**. A vacuum pump **67** may be utilized to maintain a constant pressure within the circuit, a varying pressure also being the result of gas leakage from the system.

From the above description it can be seen that a continuously operating plasma accelerator has been provided by utilizing the induction principle. It is also clear that the acceleration of a gas has been accomplished without the use of electrodes with their many inherent disadvantages. By utilizing an auxiliary high frequency coil to maintain an ionization ring in the ionization chamber, the maximum output from the driver coil is utilized. Furthermore, the auxiliary high frequency coil helps to maintain the ionization ring in the proper position such that a current induced by the driver coil is properly located within the chamber to give maximum acceleration and a minimum braking action. Utilization of the iron core in the chamber assist in maintaining the ionization ring in the proper chamber position, and additionally increases the magnetic flux density and thus the current inducing capability of the driver coil. The iron core also performs the function of causing the magnetic lines linking the current within the ionization ring to be directed radially and thus interact with circumferentially directed current within the ionization ring to provide the optimum force in the discharge direction. The accelerator is of a simple design, utilizing a minimum of parts and electrical circuitry to accomplish the desired result. The principle has many applications, certain of which have been explained here, such as an accelerator which could be utilized to accelerate gases utilized in a test chamber, for example, a wind tunnel, to accelerate a plasma for use in a low-thrust plasma propulsion engine, to pump ionizable gases, and any situation where it is necessary to motivate a gas.

What is claimed to be new is:

1. A plasma accelerator capable of producing supersonic speeds comprising: a flow chamber, means for introducing an ionizable gas into said flow chamber, means forming an ionized area in said ionizable gas; means for inducing a current in said ionized gas area; and means for directing magnetic lines linking said current-induced gas in a radial direction whereby a force is produced in the direction of plasma flow.

2. A plasma accelerator capable of producing supersonic speeds comprising: a flow chamber, means for introducing an ionizable gas into said flow chamber, high frequency means for maintaining ionized a portion of said gas; high power means for inducing a current in said ionized gas; and means having a high permeability located in said chamber whereby magnetic lines linking said ionized gas are radially directed.

3. A plasma accelerator as in claim 2 where said high-frequency means is a radio-frequency coil surrounding said flow chamber.

4. A plasma accelerator as in claim 3 wherein said radio-frequency coil has connected thereto a tuning circuit.

5. A plasma accelerator as in claim 2 wherein said high power means is an induction coil surrounding said flow chamber.

6. A plasma accelerator as in claim 2 wherein said means having a high permeability is an iron core, said iron core being constructed of a series of elements.

7. A plasma accelerator as in claim 2 wherein said high frequency means is a radio-frequency coil surrounding said flow chamber, and said high power means is an induction coil surrounding said flow chamber.

8. A plasma accelerator as in claim 2 wherein said high frequency means is a radio frequency coil surrounding said flow chamber; said high power means is an induction coil surrounding said flow chamber, and said means having a high permeability is an iron core.

9. A plasma accelerator as in claim 8 wherein said iron core is positioned in said flow chamber such that it is surrounded by said radio-frequency coil and at least a portion of said induction coil.

10. A plasma accelerator as in claim 2 wherein said high power means is an induction coil; and a tuning circuit connected to said induction coil.

11. A plasma accelerator comprising; a flow chamber having a nozzle; means for introducing an ionizable gas into said flow chamber; a radio-frequency coil surrounding said flow chamber and maintaining ionized a portion of said gas downstream from said nozzle; a driver coil surrounding said nozzle and inducing a current in said ionized gas; and an iron core positioned in said flow chamber and being surrounded by said radio-frequency coil and at least a portion of said driver coil whereby magnetic line linking said ionized gas are radially directed.

12. A plasma propulsion engine comprising: a thrust chamber having a nozzle means for introducing an ionizable gas into said thrust chamber; means for maintaining a portion of said gas ionized downstream from said nozzle; means surrounding said nozzle for inducing a current in said ionized gas; and means for directing magnetic lines linking said current induced ionized gas in a radial direction; said last-mentioned means being located within sad nozzle and downstream in said thrust chamber.

13. A plasma propulsion engine comprising: a thrust chamber having a nozzle, means for introducing an ionizable gas into said thrust chamber upstream of said nozzle; a tunable radio-frequency coil surrounding said thrust chamber downstream of said nozzle; said radio-frequency coil maintaining an ionization ring within said thrust chamber; a tunable driver coil surrounding said nozzle and inducing a current in said ionization ring; an iron core supported in said thrust chamber and extending through said ionization ring and into at least a portion of said driver coil; said iron core increasing the magnetic flux density and being positioned such that the magnetic lines linking said ionization ring are directed radially.

14. A plasma propulsion engine as in claim 13 wherein said thrust chamber is constructed of a dielectric material; said iron core is encased in a dielectric material; and said driver coil and radio-frequency coil surround the exterior of said thrust chamber.

15. A plasma propulsion engine as in claim 13 wherein said iron core is encased in a dielectric member, said dielectric member extending through a closed end of the thrust chamber and being supported by cantilever structure.

16. A plasma propulsion engine as in claim 13 wherein said iron core is encased in a dielectric member; and means positioned in said dielectric member to prevent longitudinal movement of said iron core through said driver coil.

17. A plasma propulsion engine as in claim 15, wherein said means for introducing an ionizable gas into said thrust chamber includes a manifold surrounding said dielectric casing.

18. A plasma propulsion engine as in claim 13 wherein said iron core extends from a position within at least a

portion of said driver coil to the thrust chamber open end.

19. A pump comprising: a chamber having an inlet, and an outlet; means for introducing an ionizable gas at said inlet, means for maintaining a portion of said gas ionized within said chamber forming an ionization ring, means for inducing a current in said ionization ring; and means positioned within said chamber for directing magnetic lines linking said ionization ring in a radial direction.

20. A pump comprising: a chamber having an inlet and an outlet, said chamber being stepped to form a nozzle; a high frequency coil surrounding said chamber and being located downstream of said nozzle; said high-frequency coil maintaining an ionization ring in said chamber, a driver coil surrounding said nozzle and inducing a current in said ionization ring, and an iron coil supported within said chamber; said iron core being positioned through said ionization ring and within at least a portion of said driver coil whereby magnetic lines linking said ionization rings are directed radially.

21. The method of accelerating a plasma comprising: providing a flow chamber; introducing an ionizable gas into said chamber; maintaining an ionization ring in said chamber; inducing a current in said ionization ring; and directing magnetic lines linking said ionization ring radially.

22. The method of accelerating a plasma comprising:

providing a flow chamber; introducing an ionizable gas into said flow chamber; generating a high frequency downstream of said flow chamber and thereby maintaining an ionization ring in asid flow chamber; generating a high-power current upstream of said high frequency; inducing said high-power current in said ionization ring; maintaining said induced ionization ring downstream from said point of high-power current generation; and directing magnetic lines linking said ionization ring radially.

23. A continuously operating plasma accelerator comprising: a flow chamber; means for introducing an ionizable gas into said flow chamber, high-frequency means for maintaining ionization of a portion of said gas; and a driver coil operated by a single-phase power source for inducing a current in the ionized portion of said gas.

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SAMUEL LEVINE, *Primary Examiner.*