United States Patent

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[54] **CONVERGING-BARREL PLASMA ACCELERATOR**
7 Claims, 2 Drawing Figs.

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[51] **Int. Cl.** **H01j 1/50,** H01j 7/24, H05b 1/00
[50] **Field of Search** .... 313/161, 231, 155, 231.5; 315/111; 219/75, 121 (P)

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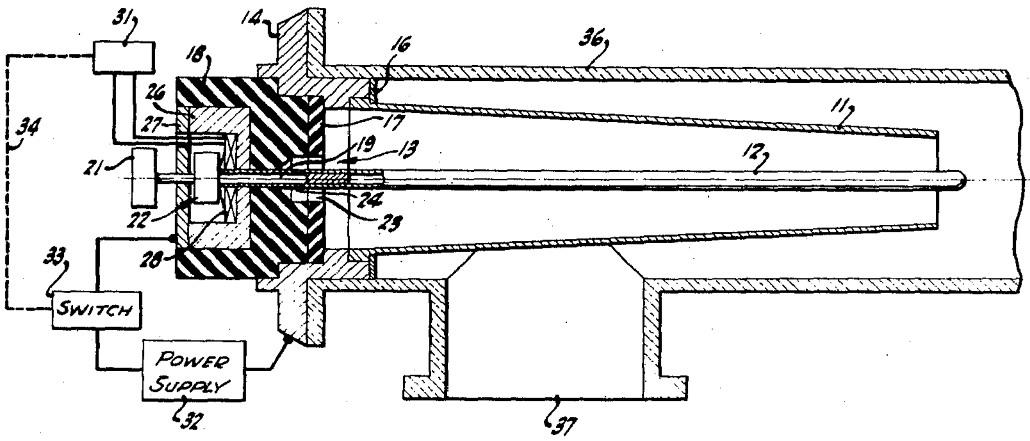
ABSTRACT: The invention comprises a device for generating and accelerating plasma to extremely high velocity, while focusing the plasma to a decreasing cross section for attaining a very dense high-velocity plasma burst capable of causing nuclear fusion reactions. A converging coaxial accelerator-electrode configuration is employed with "high-pressure" gas injection in controlled amounts to achieve acceleration by deflagration and focusing by the shaped electromagnetic fields.



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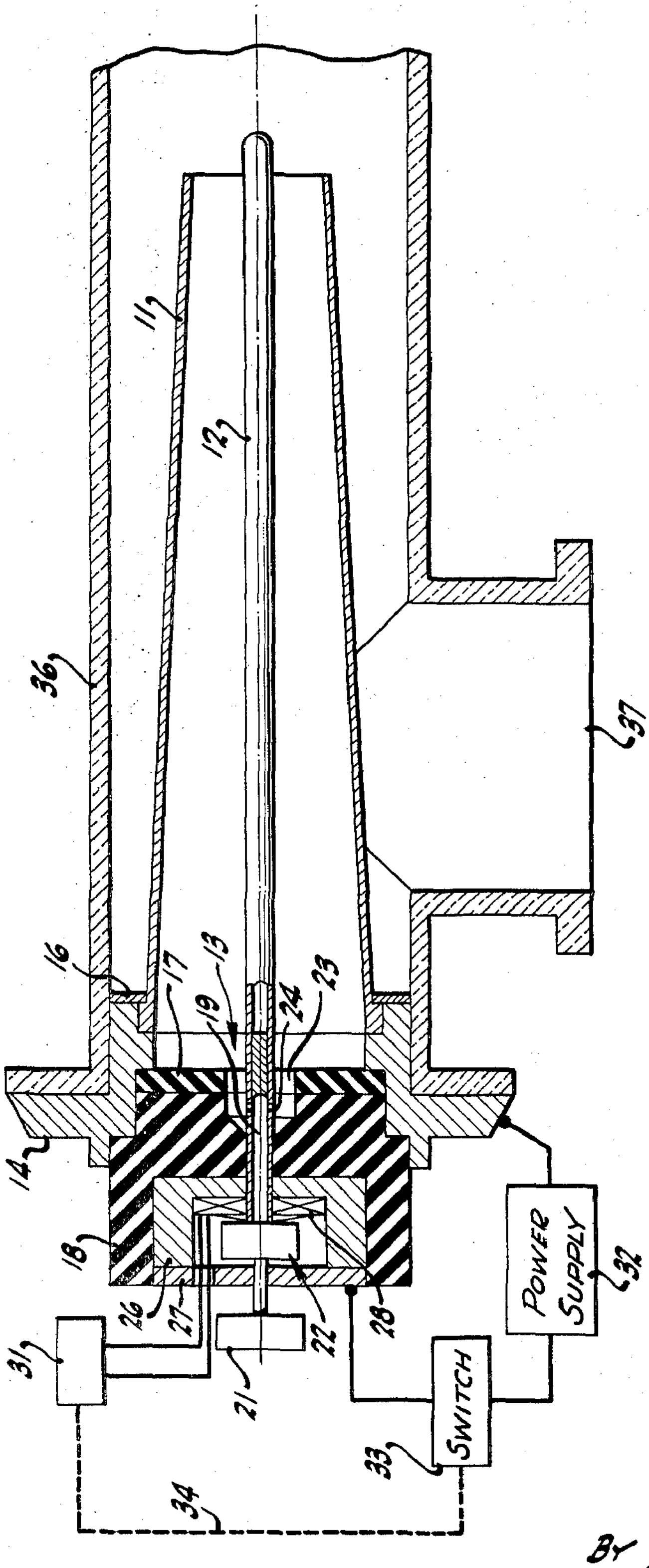

FIG. 1

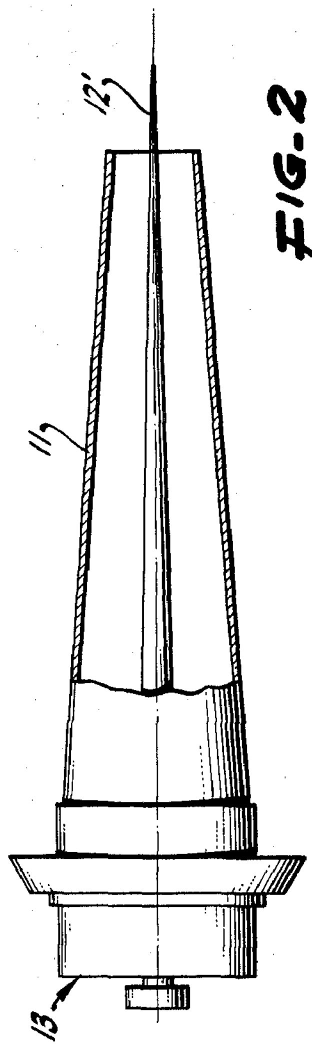

FIG. 2

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CONVERGING-BARREL PLASMA ACCELERATOR

BACKGROUND OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 850568 (72 Stat. 435; 42 U.S.C. 2457).

In the field of plasma generation, it is well known to employ coaxial structures with the central electrode comprising a cathode: such generators, commonly termed "plasma guns," operate not only to generate a high-intensity plasma but also to accelerate it, and of those which provide any type of plasma focusing, it is common to employ a magnetic-pinch mechanism beyond the cathode tip. Acceleration is commonly obtained by magnetohydrodynamic means creating a strong shock. Difficulties with this prior-art approach are found in the high radiation losses and the limitations upon speed at which the particles can travel. Plasma particles cannot travel at a higher speed than the shock velocity under these circumstances, and it is noted that the shock velocity is limited, being effected both by the gas pressure in front of the shock and the magnetic pressure behind the shock. The majority of the driving current is carried within the shock front and measurements show that a typical velocity for plasma guns of this type is 5×10^7 cm./sec. Unfortunately, this velocity is less than that required to cause nuclear fusion reactions to occur at a rate which is of practical interest.

Although many prior-art plasma generators and accelerators are highly satisfactory for their intended purposes, it is noted that acceleration should provide a maximum amount of total input energy as directed kinetic energy. Magnetic-pinch acceleration is inherently limited in the directed velocity of the high-density plasma and, as noted above, this limit is less than that required for producing nuclear reactions at appreciable rates. In addition, it is noted that shock acceleration produces radiation losses which will be seen to further reduce the energy available as kinetic energy.

The foregoing comments are directed to high-energy plasma generators and accelerations, although it is realized that various other types of devices in this field do exist. In general, these other devices are directed primarily to the generation of plasmas and to their general expulsion from the generation area. It is also conventional for such devices to expel the plasma in a diverging stream. Although the present invention may be reversed to produce a diverging plasma stream, it si primarily directed to the provision of a converging plasma traverse for focusing of the plasma generated. As noted above, this is highly advantageous in many applications. For example, the plasma generator and accelerator of the present invention produce a dense, focused pulse of plasma having a velocity greater than 10^8 cm./sec., and the density may be greater than 10^{17} particles per cm.^{3}. Prior-art plasma generators seldom achieve a velocity in excess of 2×10^7 cm./sec., and this is insufficient for initiation of fusion reactions in appreciable amounts. The present invention, on the other hand, produces a plasma pulse of sufficient density and velocity to cause fusion reactions in appreciably greater amounts.

SUMMARY OF INVENTION

There is provided by the present invention a converging coaxial plasma accelerator structure, with plasma being generated at the large end thereof and expelled from the small end. The structure is evacuated to a high vacuum, and a small controlled amount of gas is admitted to the large end of the structure into a small chamber or pocket which serves as a reservoir for gas particles during plasma generation. As the relatively high-pressure gas front moves from the aforementioned chamber into the area between the coaxial electrodes, discharge occurs by virtue of a high-voltage power supply connected between the electrodes. A high-density plasma is thus formed, and by a process similar to that experienced during combustion such plasma is accelerated away from the area of generation. Plasma focusing is accomplished by the curved electromagnetic field produced by the converging configuration of the surrounding anode structure, so that there is ejected from the small end of the accelerator a puff, or burst, of high-density plasma traveling in converging stream to thus focus at some predetermined point downstream from the device itself.

While the present invention is highly advantageous in the initiation of fusion reactions, it is also well suited to other applications such as, for example, a thruster having a high specific impulse and a substantial thrust. The present invention is not limited by the the theory of acceleration employed; in addition, it is highly advantageous because of the simplicity of structure utilized for focusing.

DESCRIPTION OF FIGURES

The invention is illustrated as to particular preferred embodiments in the accompanying drawing, wherein:

FIG. 1 is a central longitudinal sectional view of a preferred embodiment of the present invention schematically illustrating electrical circuitry associated therewith, and

FIG. 2 is a partial sectional view of an alternative embodiment of the present invention without the evacuated envelope.

DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the present invention illustrated in FIG. 1 of the drawing comprises a truncated conical shell, or anode 11, with a cylindrical rod cathode 12 disposed axially therethrough, and insulating means 13 across the large end of the anode in closing relationship thereto and electrically insulating the cathode from the anode. More specifically to the structure illustrated, it will be seen that the conical anode is mounted at the large end thereof upon an annular mounting means 14, as by means of a mounting ring 16 secured by any suitable means to the mounting means and engaging a flange about the large end of the anode which may fit into an annular recess in the mounting means, as shown. The insulator 13 may be actually comprised as an inner insulating plate 17 formed of quartz, or the like, and an insulting block 18 formed, for example, of a clear plastic. The insulating plate 17 is shown to be disposed within the mounting means 14 against an internal shoulder thereabout, and the insulating block 18 is shown to, in part, fit within the mounting means 14 against the insulating plate.

The elongated cylindrical cathode rod 12 is carried by the insulating block 18, so as to be maintained in axial alignment with the conical anode in extension therethrough. Suitable connecting means may be provided to insure firm mounting of the insulating block upon the mounting means, and the above-described elements forming the closed end of the device are suitable fitted together, or provided with appropriate seals, to prevent passage of air or gas through the large end of the anode. There is provided means for injecting a burst of gas into the chamber formed by the conical anode at the large end thereof. A gas conduit may be provided by a central bore 19 in the cathode rod 12. More specifically to the supply of gas, there is provided a gas source 21 connected through a valve 22 to hollow cathode rod. A chamber 23 is formed in the insulating means 13 about the cathode rod 12 at the large end of the device. Gas is initially directed in a puff, or burst, into this chamber, as, for example, through small radial apertures 24 in the cathode rod communicating with the central bore 19 thereof. It is of particular importance to the present invention that the gas to be ionized is originally directed into a camber that is open to the interior of the anode but which is out of the direct electric field between cathode and anode. This is discussed in greater detail below; however, it will be noted that the particular structure illustrated in FIG. 1 does provide this type of gas entry.

The gas valve 22 may be mounted in a block 26 inset in the rear of the insulating block 18 with a cover plate 27 completing the mounting. A controlled amount of gas is inserted into the large end of the device, and the valve 22 serves to accomplish this control. This valve is preferably formed as a valve disc actuated by a high-speed solenoid, and windings 28 are illustrated as a portion of the valve. Precise control over valve operation may be attained, for example, by discharging a capacitor across the valve windings and damping oscillations, so that a single impulse is delivered to the valve disc. Circuitry for operation of the valve is schematically illustrated at 31 of FIG. 1.

Electrical energization of the plasma generator and accelerator of the present invention is provided by some type of power supply 32 which may, for example, comprise a capacitor bank electrically connected between the anode and cathode. As illustrated, these electrical connections may extend from the mounting means 14 which is in electrical contact with the anode to the rear cover plate 27 which will be seen to be in electrical contact with the cathode through the mounting block 26. It is possible to initiate discharge in the device by electrical breakdown in accordance with Paschen's law as the burst of gas enters the volume between anode and cathode. Alternatively, it is possible to provide switching means 33 for connecting the power supply between anode and cathode. It is latter instance wherein some type of switching means is employed, it is preferable to interlock the valve operation with the power supply switch, as schematically illustrated by the dashed line 34 in FIG. 1. A time delay interlock is provided in this instance, so that the anode-cathode voltage is applied slightly later than the valve actuation, in order that gas will be entering the anode at the time of voltage application.

It is to be appreciated that a high voltage is applied between anode and cathode, and such voltage may, for example, be of the order of 15 kv., but it is not intended that such energization shall continue, for it is only necessary herein that the gas be initially ionized and expelled in a burst. It is for this reason that it is quite convenient to employ a capacitor bank as the power supply and to recharge such a bank for each instance of operation of the invention.

Considering now the operation of the present invention, it is first noted that the device is intended to be operated in a very high vacuum, as, for example, of the order of 10^{17} mm. Hg. Of course, only the forward portion of the device, including the anode and cathode, needs be maintained at this vacuum; and there is illustrated a vacuum envelope 36 engaging the mounting means 14 and extending forwardly thereof about the anode and cathode, with a pump-out connection 37 on the side thereof, for establishing the requisite high vacuum noted above. In the illustration of FIG. 1, the envelope 36 is only shown in part, but, of course, it is to be understood that is does extend to such target or window as may be employed with the present invention. A gas, such as hydrogen, is provided from the source 21 and is expelled by the valve 22 as a "puff" of controlled volume so as to traverse the bore 19 in the cathode and enter the chamber 23 through the small radial apertures 24. This chamber, or pocket, 23 serves as a gas reservoir for the device: it will be seen that the chamber is fully open to the large end of the anode. Relatively high-pressure gas thus leaves the chamber and proceeds rapidly into the volume between anode and cathode, whereas discharge may be accomplished merely by electrical breakdown in accordance with Paschen's law. High-voltage discharge through the gas causes ionization thereof to produce a plasma at the large, or "breech," end of the accelerator or gun. Plasma generation is relatively conventional, and, as noted above, initiation of discharge may be alternatively accomplished through switching means for applying the discharge voltage between anode and cathode at a predetermined time delay after actuation of the control valve 22. Acceleration of the plasma is herein accomplished by deflagration in that the plasma comprising ions and electrons is formed in a relatively high-pressure region, and is accelerated therefrom much like an explosion so as to be expelled into a low-pressure region wherein a negligible number of collisions occur to impede plasma progress. Consequently, the plasma travels faster than the driving current wave. Immediately prior to breakdown, or discharge, through the gas, there is an electrostatic field existing normal to the anode and cathode surfaces. As breakdown occurs, there is produced a current-induced electromagnetic field that is normal to the local electrostatic field. The plasma is accelerated in the direction dictated by the vector combination of the local electrostatic and electromagnetic field. In the present invention, a focusing of the plasma is produced when the vector electrostatic field assumes a curved shape, because of the conical boundary of the field established by the illustrated configuration of the anode. Consequently, the plasma generated at the large, or breech, end of the gun, or accelerator, is accelerated longitudinally out of the device through the small end of the anode in a converging trajectory. Again, it is noted that the illustration of the invention in FIG. 1 does not show ultimate utilization of the focused plasma; in this respect it is believed evident that utility of a high-velocity, dense burst of plasma is well known in the art. It is further noted that the vacuum envelope 36 extends to a target, or window, so that evacuation of the envelope through the port, or manifold, 37 does maintain the above-noted high vacuum therein.

Extensive testing of the present invention has established the focusing of plasma bursts within the gun, or accelerator, thereof. Targets placed at the distance along the axis of the anode and displaced therefrom clearly show the focusing effect when bombarded with plasma bursts from the accelerator. Not only is the present invention a theoretical advancement in the art, but, in addition, it is an actual practical improvement which is at the present time being employed in the art. A number of accelerators in accordance with the present invention have been built and are presently in use.

The invention as described in connection with FIG. 1 above is a truly practical improvement in the field of plasma generation and acceleration. Commonly, the invention is operated in such a manner that the amount of gas in the reservoir, or chamber, 23 is sufficient to feed the discharge until the electrical energy in the power supply 32 is dissipated. It is noted above that such power supply normally comprises a capacitor bank charged by a source of electrical energy and discharging either automatically or in time-delayed relation to operation of the valve 22, in accordance with switching means 33. For repetitive use of the present invention, provision is made for recharging the capacitor bank and repeating operation of the invention as described above.

Although the invention is illustrated in FIG. 1 as having a cylindrical rod-shaped cathode 12, disposed axially of the truncated conical anode, it is noted herein that the cathode itself may also be conical in shape. Such a configuration is illustrated in FIG. 2 of the drawing. All of the components at the large end of the device may be the same in FIG. 2 as those described in FIG. 1, and thus in FIG. 2 there is only illustrated the general external configuration of the device, with a portion broken away to illustrate the conical cathode 12'. No attempt is made in FIG. 2 to illustrate circuitry associated with the device, for such is believed to have been described in sufficient detail in connection with FIG. 1. Operation of the embodiment of FIG. 2 is substantially identical to that of FIG. 1; however, it is found that the desired accelerating field is established with the conical electrode of FIG. 2, as well as with the cylindrical electrode of FIG. 1.

Although the present invention has been described and illustrated with respect to particular preferred embodiments thereof, it is not intended to limit the invention to the details of illustration or particular terms of description. Reference is made to the appended claims for a precise delineation of the true scope of this invention.

I claim:

1. An improved plasma accelerator comprising
a hollow truncated conical first electrode,
means evacuating said first electrode,
a central rod electrode disposed coaxially of said first electrode out of contact therewith,

insulating means engaging said first electrode at the large end thereof and mounting said rod electrode,

means defining a small chamber openly communicating with the interior of said first electrode at the large end thereof and insulated from at least one of said electrodes,

means for rapidly injecting a small controlled amount of gas into said chamber, and

high-voltage supply means connected between said electrodes for establishing electrical discharge between electrodes as gas enters said first electrode from said chamber to ionize the gas and form a plasma that very rapidly travels through said first electrode toward a focus.

2. The accelerator of claim 1 further defined by said first electrode comprising an anode, said rod electrode comprising a cathode, and said rod electrode having a tapered configuration with a decreasing cross section toward the small end of said first electrode.

3. The accelerator of claim 1 further defined by said insulating means defining said small chamber as an annular depression about said rod electrode beyond the large end of said first electrode.

4. The accelerator of claim 3 further defined by said rod electrode being apertured to receive said burst of gas and substantially evenly distribute said gas in said chamber.

5. The accelerator of claim 1 further defined by said first electrode having a taper in the range of 3° to 5°.

6. The accelerator of claim 1 further defined by said means for injecting gas including a solenoid-operated disc valve and a pressurized gas source connected through said valve to said chamber.

7. An improved plasma generator and accelerator comprising

a hollow conical anode having open ends,

means for evacuating said anode to a high vacuum,

a conical cathode disposed coaxially within said anode with the small cathode end adjacent the small anode end,

insulating means closing the large end of said anode and mounting said cathode therein,

said insulator defining an annular chamber about said cathode at the large end of said anode,

means including a rapid-acting valve introducing a limited amount of gas into said chamber uniformly thereabout whereby the gas expands as a high-pressure front into the region directly between said anode and cathode, and

a high-voltage power supply connected between said anode and cathode for establishing electrical breakdown therebetween as said gas expands from said chamber to ionize the gas and produce a plasma that travels through said anode toward a focus.