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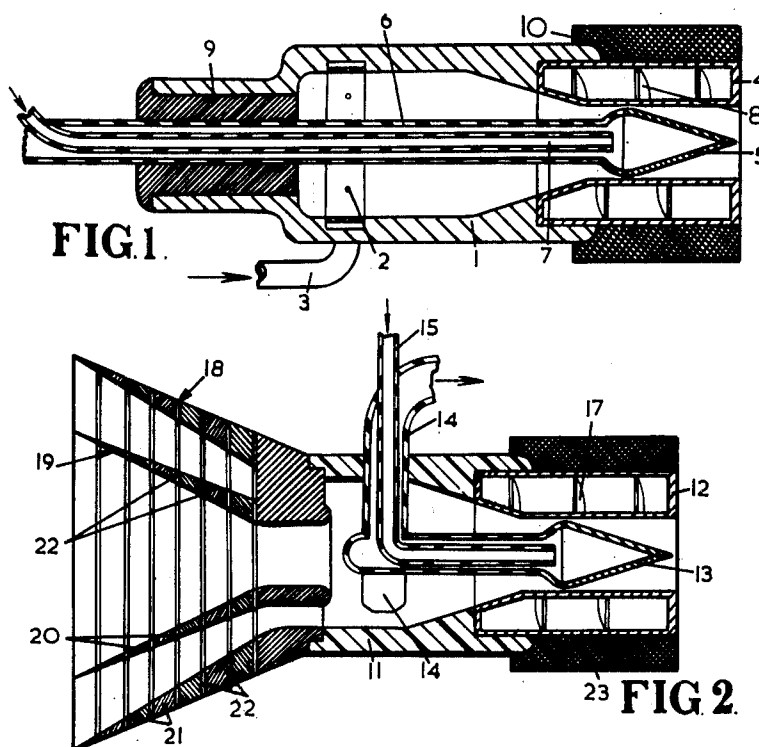
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APPARATUS FOR PRODUCING A HIGH VELOCITY JET CONSISTING OF
A PLASMA OF IONS AND ELECTRONS

Filed July 11, 1960

2 Sheets-Sheet 1



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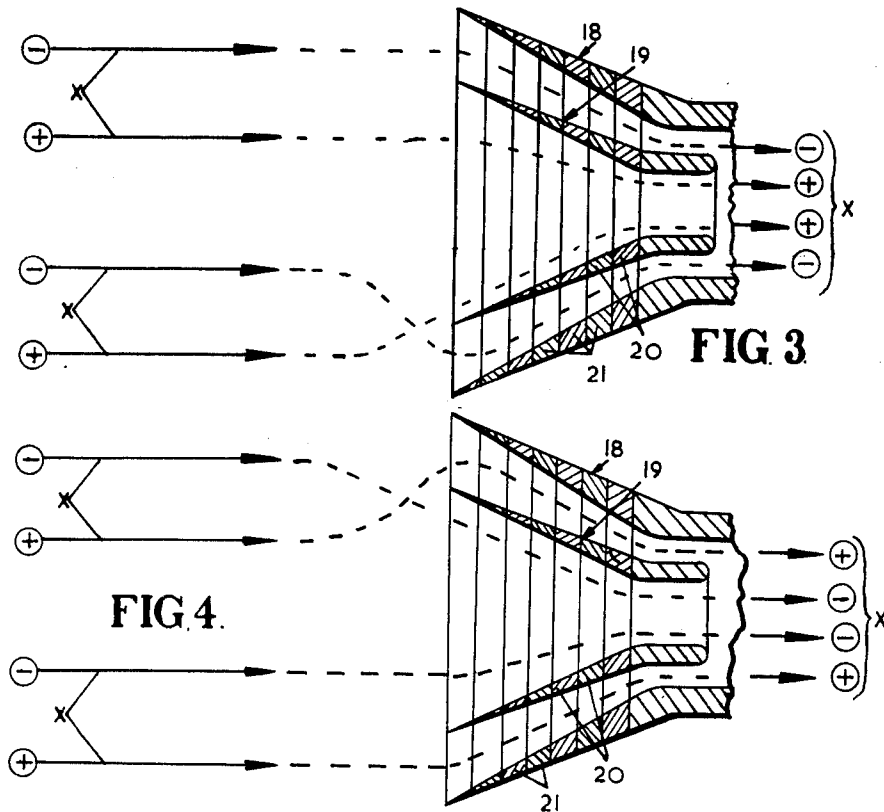
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APPARATUS FOR PRODUCING A HIGH VELOCITY JET CONSISTING OF A PLASMA OF IONS AND ELECTRONS

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7 Claims. (Cl. 313—230)

The invention relates to apparatus for producing a high velocity jet consisting of a plasma of ions and electrons. The term plasma is used herein, as in the theory of magnetohydrodynamics, to mean a mixture of ions and electrons obtained from a vaporized or gaseous working fluid at very high temperatures, for example of the order of 10,000° K. Proposals have been made to produce a very high velocity plasma jet by means of an electric arc or high frequency discharge. An object of the present invention is to provide improved apparatus whereby a plasma jet can be used for propulsion of a body or for producing a very high temperature jet for other purposes.

According to the invention the apparatus comprises a chamber having inlet means for the introduction into the chamber of a working fluid, an annular nozzle, forming an outlet from the chamber and formed from a pair of concentric electrodes, and means whereby an electrical potential is, in operation, applied across the electrodes to produce an arc therebetween capable of heating and ionising the working fluid.

Preferably the electrodes are hollow and have inlet and outlet pipes for the circulation therethrough of a coolant. The inner electrode is conveniently the cathode and the outer electrode the anode. The cathode may be of pear-shape and be arranged with its apex downstream, in which case the anode would be cylindrical or frusto-conical and arranged to co-operate with the cathode to form an annular convergent-divergent nozzle.

An electrical coil may be positioned concentrically around the anode and be connected to an electrical supply capable of producing a magnetic field which will accelerate the charged particles forming the plasma as they pass through the nozzle.

Two embodiments of the invention will now be described with reference to the accompanying drawings in which:

FIGURE 1 shows an axial sectional view of the first embodiment;

FIGURE 2 shows an axial sectional view of the second embodiment; and

FIGURES 3 and 4 are diagrams showing the flow of charged particles of gas into the apparatus shown in FIGURE 2.

Referring firstly to FIGURE 1, the apparatus comprises a cylindrical body 1 defining a chamber having at one end thereof a ring of tangentially-directed inlets 2 supplied with working fluid through an inlet pipe 3. The working fluid may be either gaseous or liquid and may be for example the products of combustion from a rocket combustion chamber. At the other end of the body 1 there is a pair of concentric electrodes 4 and 5. The radially-outer electrode 4 is the anode and has a flared upstream and a very slightly tapered divergent down-

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stream end. The inner electrode 5 is the cathode and is pear-shaped and co-operates with the inner surface of the anode 4 to form an annular convergent-divergent nozzle. The anode and the cathode are connected to an electrical source of suitable rating, such that an arc will occur between the electrodes at the throat of the nozzle. Due to the concentric arrangement of the electrodes, the arc is annular, or at least extends around a major part of the annular space between the electrodes at the throat of the nozzle. The electrical supply for producing the arc may be A.C. or D.C. Due to the very high temperature of the arc provision is made for cooling the cathode and the anode. The anode 4 is hollow and contains a helical wall 8 forming a cooling passage through which a coolant is circulated. The cathode 5 is also hollow and is integral with or connected to an axially extending tube 6 containing an internal concentric tube 7 communicating with the inside of the cathode. Coolant is passed through the inner tube into the cathode 5 and is returned through the radially-outer tube 6. A suitable coolant is liquid metal, e.g., sodium, potassium or mercury. Part of the coolant can be tapped from the tubes 6 or 7 and injected into the inlet pipe 3 to form the working fluid. The tubes 6 and 7 are supported by an insulating block 9 at the upstream end of the body 1.

The working fluid is heated and ionised in the region of the arc and is exhausted through the nozzle between the electrodes and can be used as a source of very high temperature of the order of 10,000° K. or to produce useful thrust. It is expected that an electrical supply of 100 kw. would produce approximately 300 grms. of thrust and in this connection it should be remembered that a thrust of say 300 grms. when applied for a month to a vehicle in space and weighing 10 tons could produce a terminal velocity of the order of 10,000 m.p.h.

Thrust control can be obtained by moving the central electrode relatively to the outer electrode, thereby altering the radial dimensions of the annular gap between the electrodes and the shape of the nozzle. The thrust can also be controlled electrically by varying the power input to the arc.

In the embodiment shown in FIGURE 1, the anode 4 is surrounded by an electric coil 10, which, in operation, produces a magnetic field which controls the flow of charged particles through the nozzle. The current for the coil 10 may be obtained directly from a power source or it may be energised by the arc current, by connecting the coil 10 in series with the electrodes. The magnetic field produced by the coil 10 assists to initiate the breakdown, in the throat of the nozzle, by driving high frequency sparks, supplied by a spark starter, not shown, around the annular gap between the electrodes. The coil 10 also assists cooling of the outer electrode 4 by constricting the plasma in the nozzle area by causing an electro-magnetic pinch effect, which forces the plasma away from the outer wall of the nozzle, i.e., the inner surface of the electrode 4.

In spite of the cooling arrangements and the pinch effect produced by the coil 10 it may be necessary to use a composite material for the surfaces of the electrodes instead of normal materials used in conventional heavy electrical engineering practice.

Referring to FIGURE 2, the second embodiment is a modification of that shown in FIGURE 1 and is termed

herein "a pulsed electro ram-jet" and is intended to operate, in regions of space in which there is concentrated ionisation, in a way analogous to that in which a ram-jet is used within the earth's atmosphere.

The pulsed electro ram-jet comprises a body portion 11 defining a chamber for working fluid. The body 11 has at its downstream end an anode 12 and cathode 13 which are similar to electrodes 4 and 5 respectively of FIGURE 1. The electrodes are cooled by similar means, the coolant pipes for the cathode being denoted by references 14 and 15 respectively and the internal helical wall inside the anode being denoted by reference 17. The radial portions of the pipes 14 are supported in the chamber 11 and so positioned that the restriction by them to the flow of working fluid is kept to a minimum. Working fluid is introduced into the body portion 11 through what is termed herein as a "particle separator and accelerator" positioned at the upstream end. This comprises two frust-conical concentric, co-axial tubes 18 and 19, each formed from axially spaced concentric electrically-conductive rings 20, 21 respectively. The rings 20 and 21 are separated from adjacent rings by alternately arranged rings 22 of insulating material. Potentials are applied to the rings 20 and 21 respectively of each of the tubes at increasing magnitude in the direction of flow into the chamber 11. The potentials applied to the rings 20, 21 are pulsed and the polarity of all the rings of each tube is reversed at each successive pulse.

Ions and electrons, which are present naturally in concentrated ionisation regions in space, move towards the entrance to the tubes 18 and 19, in the direction of arrows X in FIGURES 3 and 4, and are accelerated and separated depending on their polarity, by the electric fields which are produced by the potentials applied to the rings 20, 21 which form the tubes 18 and 19. The flow pattern followed by the ions and electrons through the particle separator and accelerator is shown in FIGURES 3 and 4. In FIGURE 3 the rings 21 of the outer tube are all positive and the rings 20 of the inner tube are all negative. In FIGURE 4 the rings 21 of the outer tube are all negative and the rings 20 of the inner tube are all positive. The potential applied to the electrodes 12 and 13 is maintained constant and is not pulsed. In operation, electrons and positive ions are alternately drawn in through the inner and outer tubes 18 and 19 and enter the chamber in the body 11. Due to the pulsing and the gradual increase in potential of the rings 20, 21 in the downstream direction, the ions and electrons arrive in the region of the arc at different times where they receive an increase in energy. A coil 23 surrounding the anode 12 is supplied with a pulsed current and this is phased such that the successive groups of particles arriving in the region of the magnetic field of the coil 23 are accelerated. The particles then leave the jet nozzle at very high velocity and produce useful thrust, as in the first embodiment.

What we claim as our invention and desire to secure by Letters Patent of the United States is:

1. Apparatus for producing a high velocity jet consisting of a plasma of ions and electrons, the apparatus comprising a chamber, inlet means to said chamber for the introduction into the chamber of a working fluid, and a pair of concentric electrodes, together defining an annular convergent-divergent nozzle forming an outlet from the chamber, the nozzle having an upstream convergent portion, a downstream divergent portion and a throat therebetween, the flow through the nozzle being axial, the apparatus also comprising means whereby an electrical potential is applied across the electrodes to produce an arc extending therebetween radially at right angles to the longitudinal axis of the throat and capable of heating and ionising the working fluid.

2. Apparatus as claimed in claim 1 in which the inner electrode is the cathode and the outer electrode is the anode.

3. Apparatus as claimed in claim 2 in which the cathode is of pear-shape and is arranged with its apex downstream and the anode is cylindrical at least in the region of said annular convergent-divergent nozzle.

4. Apparatus for producing a high velocity jet consisting of a plasma of ions and electrons, the apparatus comprising a chamber, inlet means to said chamber for the introduction into the chamber of a working fluid, and a pair of concentric electrodes, together defining an annular convergent-divergent nozzle forming an outlet from the chamber, the nozzle having an upstream convergent portion, a downstream divergent portion and a throat therebetween, the flow through the nozzle being axial, the apparatus also comprising means whereby an electrical potential is applied across the electrodes to produce an arc extending therebetween radially at right angles to the longitudinal axis of the throat and capable of heating and ionising the working fluid, the inner electrode being the cathode and the outer electrode being the anode, an electrical coil positioned concentrically around the anode and means connected to said coil, whereby an electrical current is applied to the coil, thereby to produce a magnetic field which accelerates the charged particles forming the plasma as they pass through the nozzle.

5. Apparatus for producing a high velocity jet consisting of a plasma of ions and electrons, the apparatus comprising a chamber, inlet means to said chamber for the introduction into the chamber of a working fluid and a pair of concentric electrodes together defining an annular convergent-divergent nozzle forming an outlet from the chamber, the nozzle having an upstream convergent portion, a downstream divergent portion and a throat therebetween, the flow through the nozzle being axial, the apparatus also comprising means whereby an electrical potential is applied across the electrodes to produce an arc extending therebetween radially at right angles to the longitudinal axis of the throat and capable of heating and ionising the working fluid, and a particle separator and accelerator positioned at the upstream end of the chamber and forming an inlet through which particles are introduced substantially axially into the chamber, the said particle separator and accelerator comprising a pair of open-ended, concentric, co-axial tubes, spaced apart radially from one another and each formed from a pack of alternately arranged electrically-conductive and insulating rings, and means for applying pulsating electrical potentials to each electrically-conductive ring of the tubes, the said pulsating electrical potentials increasing in magnitude in the direction of flow of the particles through the tubes and being changed in polarity at each successive pulse.

6. Apparatus for producing a high velocity jet consisting of a plasma of ions and electrons, the apparatus comprising a chamber, inlet means to said chamber for the introduction into the chamber of a working fluid and a pair of concentric electrodes together defining an annular convergent-divergent nozzle forming an outlet from the chamber, the nozzle having an upstream convergent portion, a downstream divergent portion and a throat therebetween, the flow through the nozzle being axial, the apparatus also comprising means whereby an electrical potential is applied across the electrodes to produce an arc extending therebetween radially at right angles to the longitudinal axis of the throat and capable of heating and ionising the working fluid, the inner electrode being the cathode and the outer electrode being the anode, an electrical coil positioned concentrically around the anode, means connected to said coil, whereby an electrical current is applied to the coil, thereby to produce a magnetic field which accelerates the charged particles forming the plasma as they pass through the nozzle, and a particle separator and accelerator positioned at the upstream end of the chamber and forming an inlet through which particles are introduced substantially axially into the chamber, the said particle separator and accelerator com-

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prising a pair of open-ended, concentric, co-axial tubes, spaced part radially from one another and each formed from a pack of alternately arranged electrically-conductive and insulating rings, and means for applying pulsating electrical potentials to each electrically-conductive ring of the tubes, the said pulsating electrical potentials increasing in magnitude in the direction of flow of the particles through the tubes and being changed in polarity at each successive pulse.

7. Apparatus as claimed in claim 6 in which said co-axial tubes are frusto-conical and have their smaller diameter ends adjacent the upstream end of the chamber.

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