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Bahr

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[54] **ION ENGINE**

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **60/202**, 313/231.3, 313/231.7, 313/362, 313/363, 315/39, 315/111.3, 315/111.5

[51] **Int. Cl.** **F03h 1/00**, H05h 1/18

[58] **Field of Search** 60/202; 313/63, 231; 315/39, 111; 328/233

[56] **References Cited**

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Assistant Examiner—Robert E. Garrett
Attorney, Agent, or Firm—Woodhams, Blanchard and Flynn

[57] **ABSTRACT**

In an ion engine wherein neutral gas enters into a gas discharge chamber in which it is fully ionized, wherein said gas discharge chamber is a part of a high-frequency resonator for effecting ionization of the neutral gas, having an electrostatic accelerating system closing off one end of said chamber and operating to extract ions from the gas discharge and accelerate same to create an accelerated ion beam and further having means for neutralizing the accelerated ion beam there is provided the distinctive feature of positioning the accelerating system at the open end of the high-frequency resonator.

7 Claims, 3 Drawing Figures

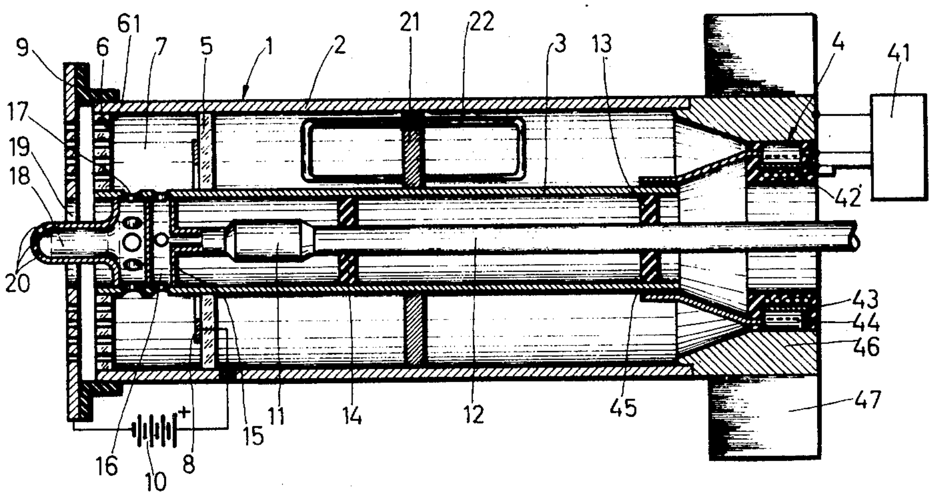


Fig. 1

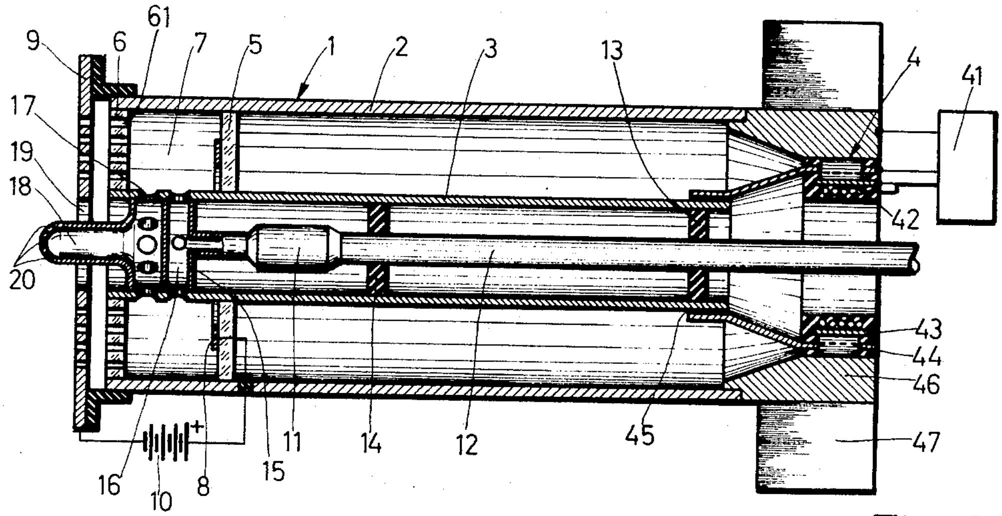


Fig. 3

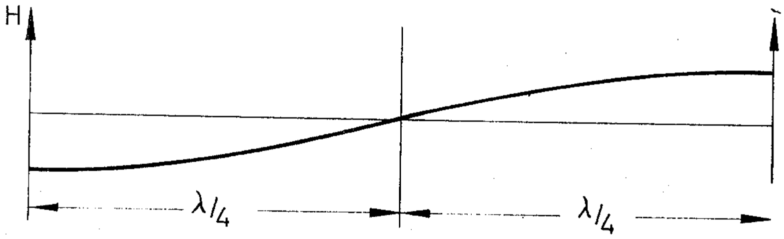
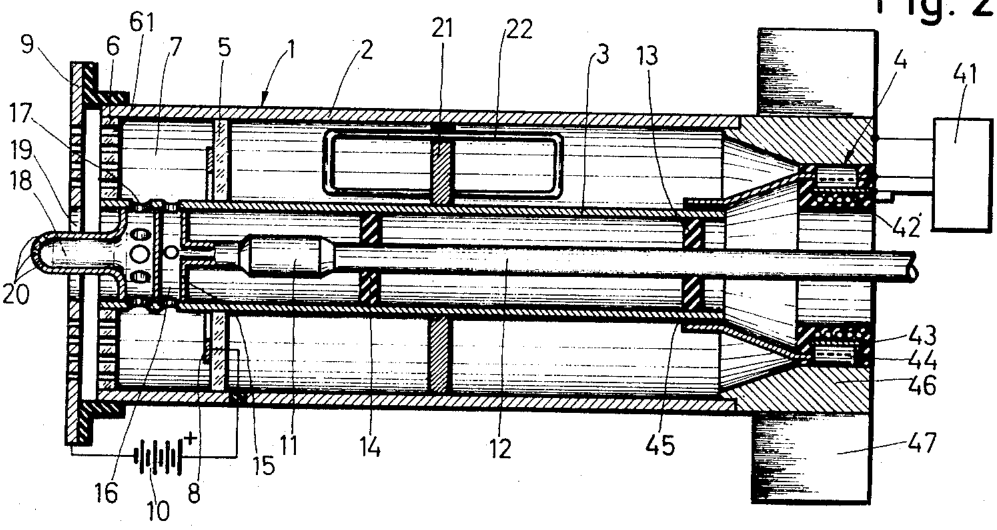


Fig. 2



ION ENGINE

FIELD OF THE INVENTION

The invention relates to an ion engine having a fuel conveying system and a gas discharge chamber into which fuel enters in gaseous form and which is part of a high-frequency resonator for effecting ionization of the gaseous fuel. The engine is further provided with an electrostatic accelerating system which in part defines the gas discharge chamber and extracts ionized gaseous fuel from the gas discharge chamber and accelerates same to create an accelerated ion beam and is also provided with a device for neutralizing the accelerated ion beam.

BACKGROUND OF THE INVENTION

This type of an ion engine is described in my copending application Ser. No. 190,981, filed Oct. 20, 1971, now U.S. Pat. No. 3,757,518, issued Sept. 11, 1973, in which arrangement the gas discharge chamber is closed off by a metallic grid plate at which the electrical high-frequency field forms a node. Thus, Lorentz forces act on the ionized gaseous fuel in the gas discharge chamber for accelerating said fuel to the grid plate whereby through the so generated axial velocity component of the ionized fuel on the grid plate a higher current density is achieved than is the case in conventional high-frequency ion engines, which, for example, are described in H. W. Loeb, State of the Art and Recent Developments of the Radio Frequency Ion Motors, AIAA Paper No. 69-285. Also the ion engine according to the aforementioned U.S. Pat. No. 3,757,518 is constructed in a simple and sturdy manner since it can be built almost entirely of metal and since in addition the electronic arrangement is simple. In addition the high-frequency losses are small in this engine because the entire high frequency energy is contained within the closed resonator and cannot radiate outwardly as in the known engine which operates with an induction coil wound around the entire discharge chamber.

Of course, Lorentz forces can become effective in the gas discharge chamber only below a certain critical pressure at which the free path length of the charge carrier exceeds at least some cycles of oscillation of the electrical field. At higher pressures, and accordingly also at higher gas densities, the collisions within the gas discharge become, however, so frequent that the free path length of the charge carrier becomes too small and the Lorentz forces are no longer effective.

SUMMARY OF THE INVENTION

The purpose of the invention is the further development of the described high-frequency ion engine while at the same time maintaining the simple and sturdy construction of the entire engine. In particular, it is the purpose of the invention to substantially increase the density of the gas discharge particularly adjacent to the accelerating electrode system in order to increase the thrust.

This purpose is attained according to the invention by arranging the accelerating electrode adjacent to the open end of the high-frequency resonator.

Thus the standing electrical wave within the high-frequency resonator forms at the end of the gas discharge chamber adjacent to the accelerating electrode a loop of oscillation and not, like in the above-described ion engine, an oscillation node. Thus the internal acceleration effect which is based on Lorentz forces in the gas discharge and accordingly the thereby additionally obtainable current density on the grid plate here intentionally is relinquished. Contrastingly, in the case of the invention, the greatest possible energy is transmitted for the ionization of the gaseous fuel within the gas discharge chamber at the open end of the resonator, so that in the vicinity of the loop of oscillation, thus at the accelerating electrode, the density of the gas discharge is at its maximum. In this manner, the current density of the accelerated ion beam is also increased so that high thrust can be produced with the ion engine according to the invention.

The construction of the ion engine of the invention is simple and sturdy because the high-frequency resonator consists entirely of metal and is energized, for example, by a common planar triode without requiring any great amount of electronic components.

BRIEF DESCRIPTION OF THE DRAWING

Further details of the invention will be disclosed in the following description in connection with the drawing, in which:

FIG. **1** is a first exemplary embodiment of a high-frequency ion engine according to the invention;

FIG. **2** is a further exemplary embodiment of an ion engine according to the invention and

FIG. **3** illustrates the shape of the standing electrical high-frequency wave H within the ion engine.

DETAILED DESCRIPTION

An ion engine **1** is built of two metallic hollow cylinders **2** and **3** which are arranged concentrically to one another and the lengths of which correspond to half of the wavelength of an electrical high-frequency field. This electrical high-frequency field is produced by means of a coaxial planar triode **4** which is located at one open end of the **λ/2**-resonator formed by the concentrical metallic hollow cylinders **2** and **3**. The planar triode together with the **λ/2**-arrangement of the hollow cylinders **2** and **3** and a DC-power supply **41** forms an oscillator circuitry, for example, the known Colpitt circuitry, and consists of a cathode **43** which is heated by a heating system **42**, a grid **44** which is connected through an isolating capacity **45** to the inner hollow cylinder **3** and an anode **46**. Further, for cooling the anode **46**, a plurality of radiator fins **47** are arranged on the periphery of the outer hollow cylinder **2**, which radiator fins **47** are used to dissipate the waste heat from within the anode **46**.

A gas discharge chamber **7** is defined on the end of the high-frequency resonator opposite the planar triode **4** by a wall **5** of dielectric material, preferably of quartz, and by a so-called grid plate **6** — of dielectric material, preferably quartz — and having a plurality of openings **61**. An annular anode **8** is arranged on the wall **5**, with which anode is associated an accelerating electrode **9** which is electrically isolated from the high-frequency resonator.

Anode **8** and accelerating electrode **9** are electrically connected through a source **10** of d.c. voltage, as a battery, which delivers an accelerating high voltage.

When the thus-described high-frequency resonator is energized, the electrical high-frequency field forms a standing electrical wave of half of a wavelength, the loops of oscillation of which lie each at the two open ends of the high-frequency resonator and the oscillation nodes of which lie in the center of the high-frequency resonator, as shown in FIG. 3.

An evaporator **11** is arranged inside the inner hollow cylinder **3**, into which evaporator liquid mercury is fed from any suitable reservoir, not illustrated, through a supply line **12**. The evaporator **11** and the supply line **12** are held in the inner hollow cylinder by electrically insulating support elements **13, 14** and **15**. The liquid mercury is evaporated in the evaporator **11** and is fed through multiple channels **16** to the gas discharge chamber **7** wherein the gaseous mercury is ionized by the high-frequency field. As can be seen from FIG. **3**, the alternating field forms a loop of oscillation near the grid plate **6**, so it is possible to withdraw the maximum energy for effecting ionization of the gas particles from the high-frequency alternating field in this region. Consequently the density and the intensity of the gas discharge will be the greatest at the grid plate.

Since a focusing effect is achieved in the gas discharge by the grid plate **6**, as is known, the positive mercury ions are extracted from the gas discharge chamber **7** and are accelerated forming an ion beam by the accelerating electrode **9** which is at a negative potential with respect to the anode **8**. It can within the scope of the invention be advantageous if, as is already known, a decelerating electrode is arranged following the accelerating electrode. This arrangement is, of course, not illustrated in the figures.

Since only the positive mercury ions are extracted from the gas discharge chamber **7**, the electrons which are generated during the ionization procedure and remain in the gas discharge chamber **7** must be removed from the gas discharge chamber **7**, in order to avoid a negative charge on the ion engine. This is advantageously accomplished by an arrangement already described in the earlier mentioned U.S. Pat. No. 3,757,518 of applicant.

For this purpose, the gas discharge chamber **7** has openings **17** on its end facing the grid plate **6**, which openings connect the discharge chamber **7** to a tube-shaped hollow member **18**. Same extends through an opening **19** of the accelerating electrode **9** and is also provided with openings **20** on its end remote from the ion engine **1**. A small portion of the mercury which is in plasma condition in the gas discharge chamber **7** is urged through the openings **17** into the hollow member **18** and further through the openings **20** towards the accelerated ion beam leaving the accelerating electrode **9** and forms thus a plasma bridge between the gas discharge chamber and the accelerated ion beam. The electrons which remained in the gas discharge chamber **7** are drawn into the accelerated ion beam through this plasma bridge, because said ion beam provides a positive anode for the electrons. In this manner the ion beam is neutralized and a negative charge on the ion engine **1** is prevented. Of course, the neutralization of the ion beam can also take place by means of a conventional hollow cathode.

A second embodiment of the invention which is illustrated in FIG. **2** differs from the described first embodiment only in that a different construction is shown for the high-frequency resonator. At the point at which in the first exemplary embodiment the standing wave of high-frequency field forms an oscillation node, the present $\lambda/2$-resonator is interrupted by a metallic partition wall **21** which is arranged between the hollow cylinders **2** and **3**. In this manner two connected $\lambda/4$-resonators are created; the one of the $\lambda/4$-resonators which contains the planar triode **4** serves thereby as a high-frequency generator producing the high-frequency energy which is coupled by means of a coupling loop **22** into the second $\lambda/4$-resonator which contains the gas discharge chamber **7** (for coupling to cavity resonators see "Electronic and Radio Engineering," fourth edition, by Frederick Emmons Terman, McGraw-Hill Book Company, Inc. (1955), at Page 164.). Operation and distribution of the high-frequency alternating field are in this exemplary embodiment the same as in the first exemplary embodiment so that in the figure for same the parts are shown with the same reference numerals.

An ion engine according to the invention is distinguished — as can be seen from the above — by a sturdy and simple construction; at the same time through the specific construction of the ion engine as a part of an open high-frequency resonator a high gas discharge density is obtained in the gas discharge chamber so that a considerable thrust can be achieved with this ion engine.

Although a particular preferred embodiment of the invention has been disclosed above for illustrative purposes, it will be understood that variations or modifications thereof which lie within the scope of the appended claims are fully contemplated.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In an ion engine with means defining a fuel conveying system and means defining a gas discharge chamber into which fuel enters in a gaseous form, means defining a high frequency resonator, said gas discharge chamber being part of said high-frequency resonator for effecting ionization of the gaseous fuel, means defining an accelerating electrode system at one end of said gas discharge chamber for extracting ionized gaseous fuel from said gas discharge chamber and accelerating same thus creating an accelerated ion beam and means for neutralizing the accelerated ion beam, the improvement comprising said accelerating electrode being arranged adjacent to said open end of said high-frequency resonator, said high-frequency resonator producing a standing wave having a node in the center of said high-frequency resonator and an oscillation loop at said open end.

2. The improvement according to claim **1**, wherein said high-frequency resonator is a $\lambda/2$-resistor wherein λ is the wave length of standing wave.

3. The improvement according to claim **2**, wherein said $\lambda/2$-resonator consists of two coupled $\lambda/4$-resonators, of which only one is used for producing the high-frequency alternating field and is connected to the other resonator by coupling elements.

4. The improvement according to claim **1**, wherein said open end of said resonator which defines said gas discharge chamber is closed by a grid plate made of dielectric material.

5. The improvement according to claim **4**, wherein said dielectric material is quartz.

6. In an ion engine having means defining a discharge chamber closed off by a perforated wall, a gaseous fuel supply system communicating with the discharge chamber and supplying thereto electrically neutral fuel in gaseous form, a high-frequency generator operable to ionize the gaseous fuel in the discharge chamber, a perforated acceleration electrode mounted in electrically insulated relation, in outwardly spaced relation to the perforated wall of the discharge chamber and pulling the ionized fuel out of the discharge chamber and accelerating the ionized fuel electrostatically to create an accelerated ion beam, and means operable to neutralize the accelerated ion beam, the improvement comprising said discharge chamber forming part of a high-frequency resonator having a cylindrical wall closed at one end by said perforated wall, said resonator containing said high-frequency generator and said fuel supply system; said high-frequency generator energizing said resonator at its given frequency and producing, in said high-frequency resonator, a standing electrical wave having a node located intermediate the ends of said resonant chamber; and dielectric means mounting said acceleration electrode on said cylindrical wall adjacent the open end of said high-frequency resonator.

7. The improvement according to claim **6,** wherein said high-frequency resonator is a $\lambda/2$-resonator, wherein λ is the wave length of the standing wave.

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