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GAS DISCHARGE ION SOURCE WITH MULTIPLE ANODE STRUCTURE AND A.C. SUPPLY MEANS

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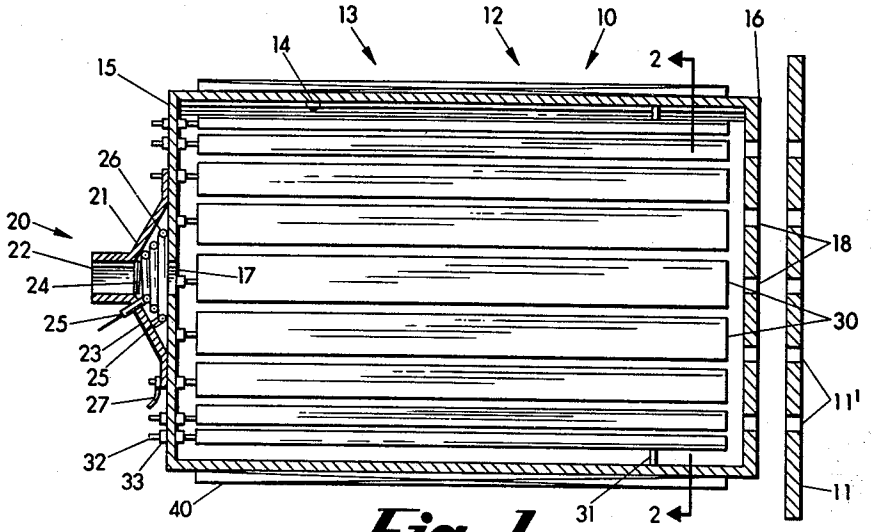


Fig. 1

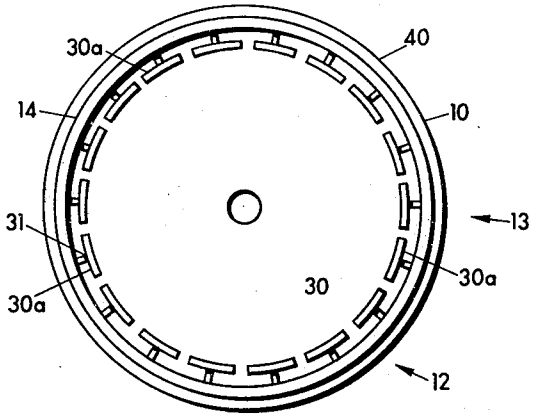


Fig. 2

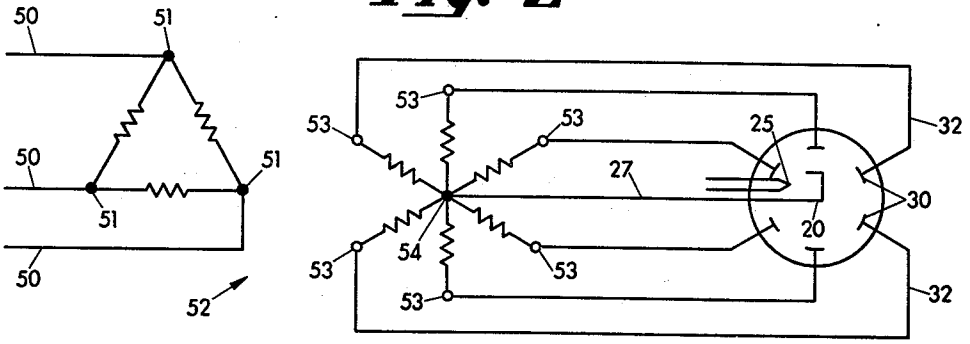


Fig. 3

INVENTOR:
GORDON SOHL

ATTORNEY:
WILLIAM A. KEMMEL JR.

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GAS DISCHARGE ION SOURCE WITH MULTIPLE ANODE STRUCTURE AND A.C. SUPPLY MEANS

Gordon Sohl, Pasadena, Calif., assignor, by mesne assignments, to Xerox Corporation, a corporation of New York

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ABSTRACT OF THE DISCLOSURE

A gas discharge ion source having a chamber containing an ionizable gas, a cathode, and at least two anodes with an alternating current power source connected between them and a constant magnetic field adapted to increase the length of the electron path between them.

In general, the present invention relates to an ion source for a device such as an ion engine. More particularly, the present invention involves a gas discharge ion source adapted to use alternating current directly while maintaining continuous arc operation with high mass efficiency.

At present, much research and development effort is being expended in the area of electrical propulsion systems for space vehicles because of the very large velocities they can produce. One electrical propulsion system is the ion engine utilizing a gas discharge ion source such as described by Speiser, et al. in "Studies of a Gas Discharge Cesium Ion Source," American Rocket Society Annual Meeting, (November 1962), and "Test Results for a Cesium Electron Bombardment Ion Motor," Institute of the Aerospace Sciences Meeting, (January 1963). As disclosed in the aforementioned Speiser, et al. papers, the process of ion production from a gas discharge ion source is due almost entirely to collisions between gas atoms and electrons with a kinetic energy greater than the ionization potential level. Thus, a continuous flow of electrons from the cathode to the anode must be maintained, i.e., an arc must be maintained, in order to maintain a high level of ion production. If, for example, the gas atoms escape in a neutral form, they are not accelerated and thus reduce the mass efficiency of the ion engine. Because of such reasons, a gas discharge ion source for an ion engine invariably utilizes direct current to maintain the arc between the cathode and anode. However, the power for operating the ion engine is available as a practical matter only in alternating current form. Consequently, at present, it is necessary to convert the alternating power to direct power when operating the gas discharge ion source for the ion engine. Such conversion not only entails a power loss but also requires additional electrical equipment which adds weight and operation problems to the total system. For this reason, it has been attempted in the past to operate the gas discharge ion source for an ion engine on alternating current using the conventional construction illustrated in the Speiser et al. papers. However, it was found that the use of alternating current with such equipment caused the arc to be extinguished during the negative half cycle of the alternating current which in turn caused neutral gas atoms to escape from the ion source and to reduce the mass efficiency of the ion source.

Consequently, an object of the present invention is a low voltage gas discharge ion source adapted to use alternating current directly.

Another object of the present invention is a gas discharge ion source comprising a chamber containing a body of gas adapted to be ionized by bombardment with

electrons. The chamber has an inlet for admitting said gas and an outlet for emitting positive gas ions. In the chamber is a cathode and at least two spaced anodes substantially spaced from the cathode. The ion source also includes means for maintaining a magnetic field in the chamber adapted to increase the length of the electron path between the cathode and anodes. The method of the present invention involves forming the aforementioned device and then connecting the lines from an alternating current power source to the primary winding of a transformer. Then, the aforementioned anodes are connected to the end taps of the secondary winding of a transformer while the cathode is connected to an intermediate tap of the secondary winding of such transformer. Finally, a discharge is initiated in the gas between the cathode and the anodes.

In order to facilitate understanding of the present invention, reference will now be made to the appended drawings of a preferred specific embodiment of the present invention. Such drawings should not be construed as limiting the invention which is properly set forth in the appended claims.

In the drawings:

FIG. 1 is an axial cross-section of a semi-schematic diagram of a gas discharge ion engine incorporating gas discharge ion source of the present invention.

FIG. 2 is a cross-sectional view of FIG. 1 taken along lines 2—2 FIG. 1.

FIG. 3 is a schematic wiring diagram of the present invention illustrated in FIG. 1 with its connection to a source of three-phase alternating current power.

As illustrated in FIGS. 1–2, the present invention is utilized in a gas discharge ion engine **10** having an accelerating electrode **11** with a plurality of apertures **11'** for ejecting the positive ions generated in the gas discharge ion source **12**. The gas discharge ion source **12** includes a cylindrical chamber **13** having a side wall **14**, a first end wall **15**, and a second end wall **16**. The chamber **13** contains a body of gas adapted to be ionized by bombardment with electrons. Preferably, the gas is composed of materials such as cesium or mercury which are adapted to be ionized by bombardment with low energy ions. Also, such gas is maintained at a low pressure in order to support the discharge between the cathode and anodes. Thus, the gas pressure is preferably in the range of about 1×10^{-3} to 1×10^{-4} mm. Hg when cesium is used. The first end wall **15** has an inlet **17** for admitting the gas to the chamber **13**. The second end wall **16** has a plurality of outlets **18** aligned with the accelerating electrode apertures **11'** for emitting positive gas ions. Thus, the end wall **16** forms a screen electrode. In the chamber **13**, adjacent to the end wall **15** is a cathode **20** which adjoins the inlet **17**. The cathode **20** comprises a cover **21** mounted on the end wall **15** and connected to a gas inlet conduit **22**. The cover **21** encloses an emitter coil **23** of refractory metal grounded to the cover **21**. Covering the emitter coil **23** and adjoining the conduit **22** is a baffle plate **24** for directing the gas flow over the emitter coil **23**. As disclosed in the above Speiser, et al. papers, the surface of the emitter coil **23** has a low work function maintained by bringing the cesium through it to form a cesium coating on the surface. The cathode **20** also includes means for heating it to initiate a discharge between it and the anodes **30**. Such means comprises a resistance coil **25** coaxially mounted within the emitter coil **23** and separated therefrom by an insulating sheath **26**. However, as noted in the abovementioned Speiser, et al. papers, by proper design, the cathode can be heated solely by power delivered by the bombardment of the positive ions from the gas onto the cathode. Such self-heating cathode operation is achieved by the combination of in-

troducing the gas into the chamber **13** by the cathode **20** as noted above and mechanically enclosing the cathode such as illustrated in FIG. 1 wherein the opening **17** between the cathode **20** and the chamber **13** is substantially smaller than the cathode cover **21**. In this way, the gas pressure adjoining the cathode is increased to promote self-heating operation. Around the exterior of the side wall **14** is a magnetic coil **40** which provides means for maintaining a substantially constant magnetic field in the chamber **13** adapted to increase the length of the electron path between the cathode **20** and the anodes **30**. The magnetic coil **40** and resistance coil **25** each have a power input lead and common leads grounded to the walls of the chamber **13**. The walls **14**, **15**, and **16** of the chamber **13** as well as the cover **21** in turn are electrically connected to a common output lead **27**. Thus, both the cathode **20** and chamber **13** are maintained at the same voltage with respect to the anodes **30**.

In the chamber **13**, substantially spaced from the cathode **20** are at least two spaced anodes **30**. As illustrated in FIGS. 1 and 2, the chamber **13** is cylindrical and there are equally spaced eighteen anodes **30** extending parallel to the axis of the chamber **13** adjacent to the chamber side wall **13**. However, as illustrated in the schematic wiring diagram in FIG. 3, the anode **30** are electrically connected in groups of threes with each member of the group being spaced apart by 120 degrees so that there is the electrical equivalent of at least six anodes equally spaced around the circumference of the side wall **14**. For example, the electrodes **30***a* are connected together to a common lead. Each anode **30** is supported by an insulating post **31** and is connected by a lead **32** through an insulating sleeve **33** to an external source of power.

To operate the gas discharge ion source **12**, the chamber **13** is constructed as set forth above with the cathode **20** at one end of the chamber **13** and eighteen anodes **30** spaced from the cathode **20** and around the side wall **14** in the chamber **13**. A substantially constant magnetic field is formed in the chamber substantially parallel with the anodes by activating the magnetic coil **40**. The lines from the power source then are connected to the end taps of the primary winding of a transformer. Specifically, as illustrated in FIG. 3, the lines **50** of three-phase alternating current power are connected to the primary delta winding taps **51** of a three-phase transformer. The six anode leads **32** are connected to the six secondary winding taps **53** of a center-tap star output of the transformer **52**. The cathode **20** is connected to the center tap **54** of the secondary winding of the transformer **52** by the output lead **27**. The emitter **23** is then heated by connecting the resistance coil **25** to an appropriate source of power and gas such as cesium vapor is admitted to the chamber **13** through the inlet line **22** and inlet **17**. Under such conditions, a discharge is initiated in the gas between the cathode **20** and the anodes **30**. When such discharge has been initiated, a portion of the positive ions produced will bombard the cathode **20** to generate sufficient heat to maintain its operation so that the power input to the emitter **23** may be cut off.

A gas discharge ion source was constructed and operated as set forth above. Specifically, an arc current of about 33 amps was set up under a voltage difference of about 7 volts with a magnetic field of about 8 gauss. Under such conditions, it was found that a beam current of 325 ma. was produced with the emitted positive ions having an energy of 3500 ev. A mass utilization efficiency of 87% was attained at an arc energy expenditure of 764 ev./ion. With such ion source, a thrust of 7.35×10^{-3} lbs. was achieved for a power to thrust ratio of 200 kw./lb. Thus, the power efficiency was 79% and an over-all engine efficiency of approximately 69% was obtained.

The rectification of the alternating current power by the discharge ion source of the present invention appears to depend on the relative mobilities of the ions and electrons in the ionized gas plasma in the chamber. Thus,

where the anodes are maintained at about 7 volts above the cathode, the ionized gas plasma has the voltage of about 1 volt above the anodes and forms a double sheath such as discussed in the above Speiser, et al. papers. Under such conditions, electrons emitted by the cathode can pass freely from the gas plasma to the anode; however, when the voltage difference is reversed, the low mobility of the ions substantially prevents them from traveling to the then negative anode. Consequently, with a single anode, the discharge is extinguished during the negative half cycle of the alternating current power. However, with at least two anodes, an anode is positive with respect to the cathode at all times so that sufficient electron current will be drawn to maintain the discharge. In addition, by utilizing at least six anodes in conjunction with three-phase alternating current power, the positive voltage difference between the anodes and the cathode is always maintained above the forward voltage drop necessary to maintain the arc between the cathode and the anode and a relatively smooth arc current is maintained.

Many other specific embodiments of the present invention will be obvious to one skilled in the art in view of this disclosure. Thus, for example, a variety of anode and cathode configurations may be utilized as long as a magnetic field may be utilized between the cathode and anode to hold the electrons sufficiently long therebetween to generate a supply of positive ions.

There are many features in the present invention which clearly show the significant advance the present invention represents over the prior art. Consequently, only a few of the more outstanding features will be pointed out to illustrate the unexpected and unusual results obtained by the present invention. One feature of the present invention is that large alternating currents may be supplied to the device of the present invention at low voltage and the power is used directly with high efficiency to form a gas discharge ion source. Thus, the need for the normally required conditioning equipment is eliminated. Another feature of the present invention is that a multiple-phase alternating current power can be supplied to a single gas discharge ion source without the need for rectifying the individual current phases. Still another feature of the present invention is that the rectification of the alternating current power occurs in the device which is resistant to radiation unlike the present widely-used solid state rectifiers.

It will be understood that the foregoing description and examples are only illustrative of the present invention and it is not intended that the invention be limited thereto. All substitutions, alterations, and modifications of the present invention which come within the scope of the following claims or to which the present invention is readily susceptible without departing from the spirit and scope of this disclosure are considered part of the present invention.

What I claim is:

1. A simple, efficient gas discharge ion source adapted to use alternating current directly while maintaining continuous arc operation with high mass efficiency comprising:

(a) a chamber containing a body of gas adapted to be ionized by bombardment with electrons, said chamber having an inlet for admitting said gas and an outlet for emitting positive gas ions;

(b) a cathode in said chamber and at least two spaced anodes in said chamber substantially spaced from said cathode;

(c) means for maintaining a substantially constant magnetic field in said chamber substantially parallel to the axis between said inlet and outlet adapted to increase the length of the electron path between the cathode and anodes; and,

(d) means fore supplying alternating current power to said cathode and anodes, connected to said cathode and anodes.

2. A gas discharge ion source as stated in claim 1 wherein said gas is cesium vapor.

3. A gas discharge ion source as stated in claim 1 wherein said gas is maintained at a pressure in the range of about 1×10^{-3} to 1×10^{-4} mm. Hg.

4. A gas discharge source as stated in claim 1 wherein said cathode is adjacent to one end wall of said chamber and adjoins said inlet so that the incoming gas contacts said cathode.

5. A gas discharge ion source as stated in claim 1 wherein said chamber is cylindrical with said anodes extending parallel to the axis of said chamber and being positioned adjacent to the chamber side wall and said cathode is positioned adjacent to one end wall of said chamber.

6. A gas discharge ion source which, as stated in claim 4, includes means for heating said inlet cathode to initiate a discharge between said inlet cathode and said anodes.

7. A gas discharge ion source as stated in claim 5 wherein at least six anodes are equally spaced around the circumference of the side wall.

8. A method of using alternating current directly from a power source to operate a gas discharge ion source with continuous arc operation and high mass efficiency comprising:

(a) containing in a chamber a body of gas adopted to be ionized by bombardment with electrons;

(b) contacting said body of gas with a cathode and at least two spaced anodes substantially spaced from said cathode;

(c) forming a substantially constant magnetic field in said chamber extending substantially parallel to the axis of said chamber, adapted to increase the length of the electron path between the cathode and anodes.

(d) connecting the lines from said power source to the primary winding of a transformer;

(e) connecting said anodes to the end taps of the secondary winding of said transformer and said cathode to an intermediate tap of the secondary winding of said transformer; and,

(f) initiating a discharge in said gas between said cathode and anodes.

9. A method as stated in claim 8 wherein the discharge between said cathode and anodes is initiated by heating said cathode.

References Cited

UNITED STATES PATENTS

3,113,427	12/1963	Meyer	313—63
3,243,954	4/1966	Cann	315—111
3,283,205	11/1966	De Bolt	315—111

JAMES W. LAWRENCE, Primary Examiner

P. C. DEMEO, Assistant Examiner

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