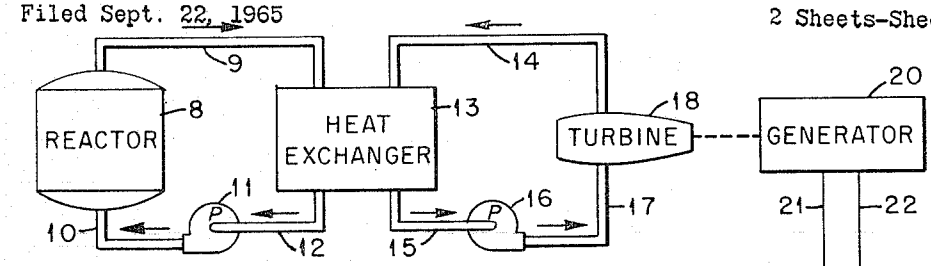
Feb. 14, 1967 O. C. YONTS 3,303,650

ION PROPULSION

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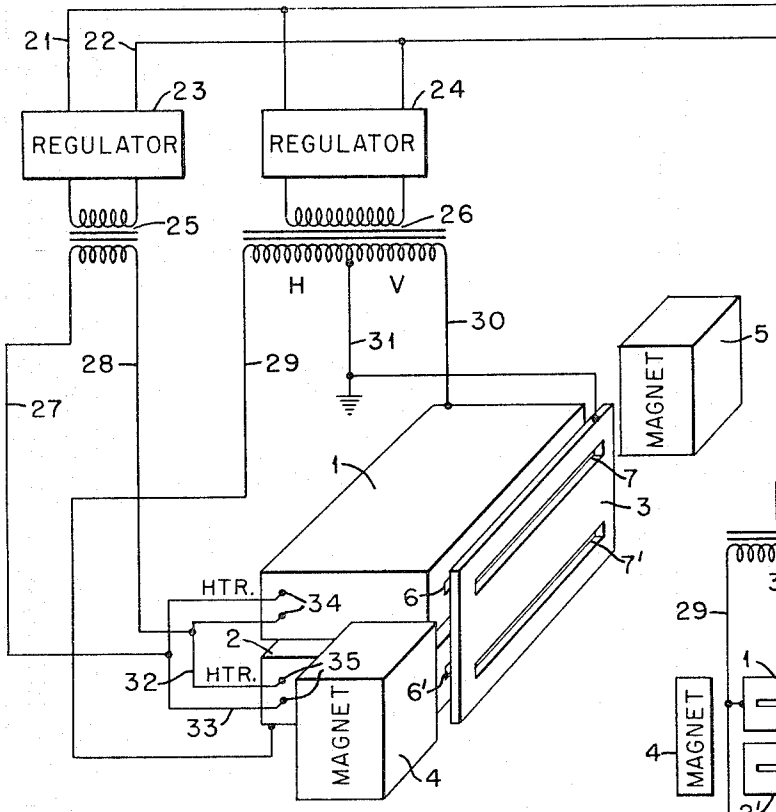


Fig. 1.

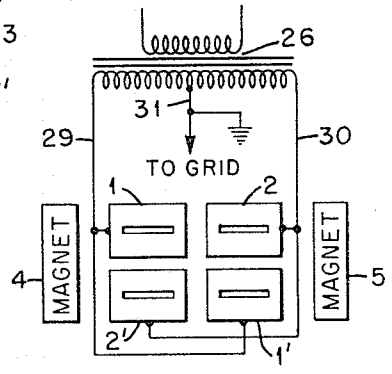


Fig. 3.

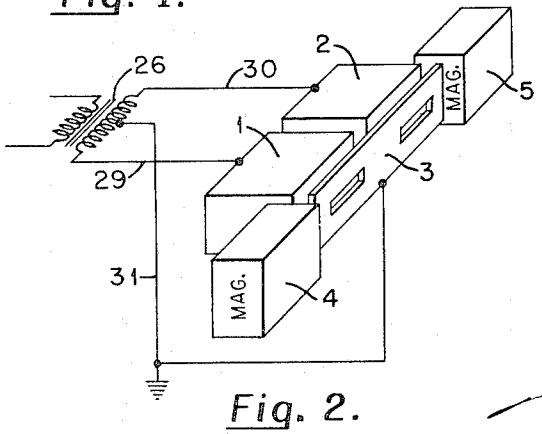


Fig. 2.

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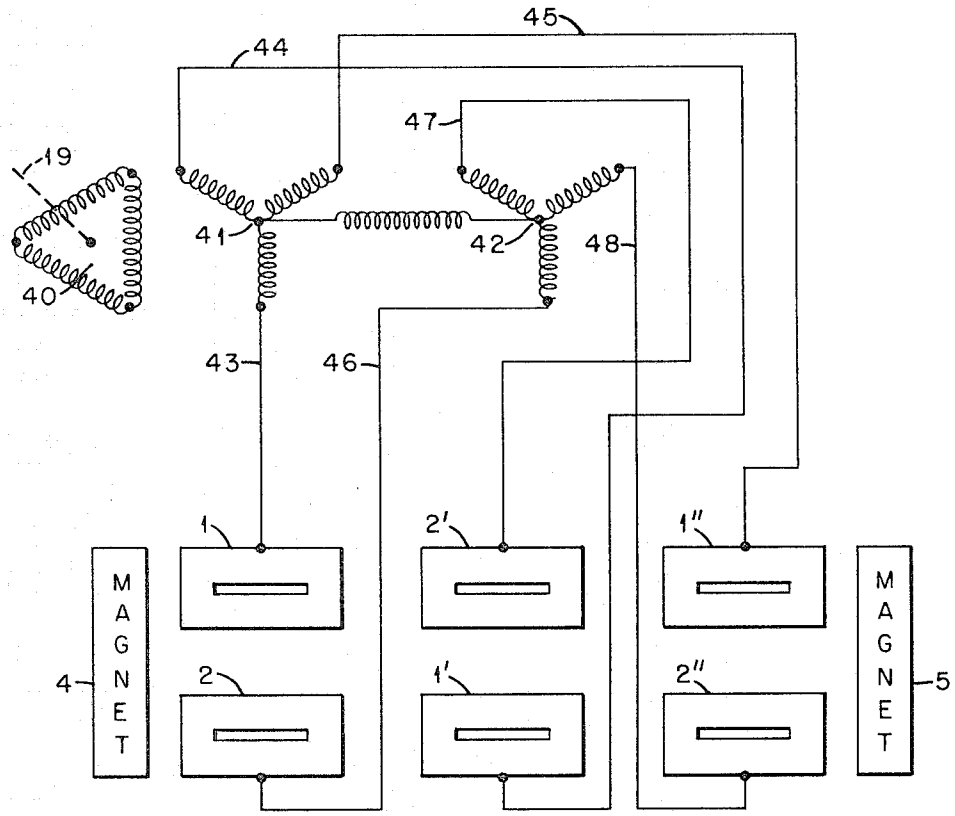


Fig. 5.

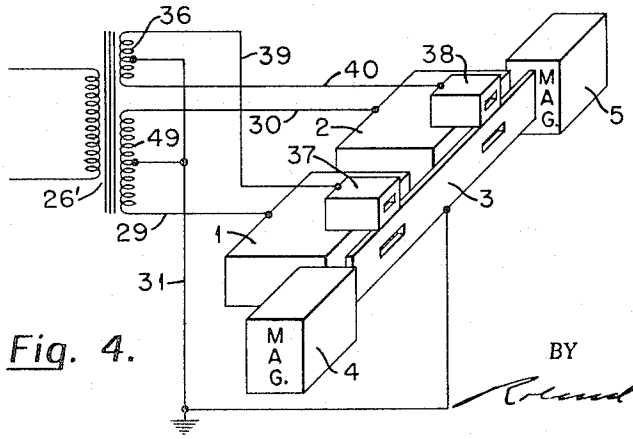


Fig. 4.

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3,303,650

ION PROPULSION

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8 Claims. (Cl. 60—202)

The present invention relates to an ion propulsion system for space vehicles wherein A.C. power is utilized for ion acceleration thus reducing the size and weight of required power supply components.

Ion sources that are presently contemplated for the propulsion of space vehicles utilize generally conventional ion source technology in that a gas or a solid is ionized, and the ions are accelerated and collimated by large D.C. potentials in a direction to impart the desired motion to the vehicle. In order to prevent a charge buildup on the vehicle, the ion beam must be neutralized by ejection of electrons from the vehicle either as a component of the beam or closely associated therewith.

Some of the drawbacks of the prior ion propulsion systems are the bulk of power supplies for producing the D.C. potentials required to achieve substantial engine thrust, the use of rectifiers which are not only bulky but also require large radiators to dissipate the heat generated thereby, and the problem of neutralizing the exhaust beam.

With a knowledge of the limitations of prior ion sources, as discussed above, it is the object of the present invention to provide an ion source system wherein A.C. power can be utilized to provide acceleration for the ions while at the same time eliminating the need for bulky rectifiers and the associated problem of removing heat caused by the use of such rectifiers.

This and other objects and advantages of the present invention will become apparent upon a consideration of the following detailed specification and the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of one system for accomplishing the above object;

FIG. 2 is a schematic diagram of another embodiment of the present invention;

FIG. 3 is a schematic diagram of still another embodiment of the present invention;

FIG. 4 is a schematic diagram of another embodiment of the present invention; and

FIG. 5 is a schematic diagram of yet another embodiment of the present invention.

The above object has been accomplished in the present invention by providing at least one pair of ion sources with a source of high frequency A.C. potential connected to the ion sources such that both ion sources would function together—one emitting positive ions and the other negative ions. As the potential changed, the outputs of the respective ion sources would reverse and, with equal outputs from each source, the net charge of the combined propulsion beam would be zero, thus alleviating the neutralizing problem. The ion source systems of the present invention do not require any D.C. source of supply, thus eliminating the need for bulky and heat-producing rectifiers.

Referring now to the drawings, in FIG. 1 a pair of ion sources **1** and **2** are mounted one above the other and are provided with ion exit slits **6** and **6'**, respectively. An ion accelerating member **3** is mounted in front of the sources **1** and **2** and this member **3** is provided with ion exit slits **7**, **7'** in alignment with the slits **6**, **6'**, respectively, of the ion sources **1** and **2**.

A pair of permanent magnets **4** and **5** are mounted, one at each of the ends of the ion sources **1**, **2**, as shown, and provide a magnetic field whose direction is parallel to the face of member **3**. The means for supplying A.C. high voltage to the ion sources and A.C. power to heaters located in the ion sources include a nuclear reactor **8**, a heat exchanger **13**, a turbine **18**, a generator **20**, a regulator **24** connected to a high voltage transformer **26**, and a regulator **23** connected to a transformer **25** for supplying heater power to the heaters of the ion sources. A heat transfer fluid which is heated by the reactor **8** is circulated by means of a fluid line **9** to the heat exchanger **13** and after passing therethrough is returned to the reactor **8** by means of a fluid line **12**, a pump **11**, and a fluid line **10** to be reheated by the reactor.

The heat exchanger **13** is connected by a water or other turbine fluid line **15**, a pump **16**, and a fluid line **17** to a turbine **18** and after the fluid passes therethrough it is returned to the heat exchanger **13** by means of a fluid line **14**. The turbine **18** drives an electric generator **20** by means of a coupling **19**. The output of the generator **20** is connected by means of leads **21** and **22** to regulators **23** and **24**. Regulator **23** is in turn coupled to a transformer **25** and the secondary thereof is connected by means of leads **27** and **28** and leads **32** and **33** to the heater terminals **34** and **35** of the ion sources **1** and **2**, respectively. Regulator **24** is coupled to a high voltage transformer **26** and the secondary thereof is connected by leads **29** and **30** to the ion sources **1** and **2**, respectively, as shown. A center tap of the secondary of transformer **26** is connected by a lead **31** to ground and to the accelerating member **3**.

Each of the ion sources **1** and **2** contains a charge material which is ionized by means of respective heaters mounted therein, not shown, with the respective heaters connected to the respective heater terminals **34** and **35**. A preferred charge material is CsCl. However, other suitable charge materials may be used, if desired, for example, CCl_4 and Cl_2. When CsCl charge material is used, it can be substantially completely ionized when it is heated to temperatures of about 1500° centigrade and above. Thus, the use of an arc discharge, normally required in most prior ion sources, is not necessary in the ion source systems of the present invention when such a charge material is utilized.

In the system of FIG. 1, an accelerating potential of about 30 kv., for example, is provided by the high voltage transformer **26**. An A.C. voltage of about 400 cycles per second, for example, is applied to the primary of the transformer **26**. Voltages to the respective ion sources are adjusted by conventional means, not shown, such that equal quantities of positive and negative ions are alternately withdrawn from the respective ion sources thereby providing a composite space charged neutralized ion beam from the ion sources.

It should be understood that the device of FIG. 1 can be used on the ground when it is desired to produce a space charged neutralized beam for use as a particle accelerator.

The device of FIG. 1 has produced positive and negative ion beams in excess of 200 ma. each, using Cl_2 or CCl_4 as the charge material, and the ions thereof will be accelerated by the member **3** to provide propulsion for a space vehicle.

It should be understood that the system of FIG. 1, as well as the other systems to be described hereinafter, is not limited to the use of the high voltage transformer **26**. For example, the use of a high voltage bi-phase generator would eliminate the need for the high voltage transformer, and only the necessary circuit breakers would be required between the generator and sources. Regulation could then be achieved by varying the load on the reactor **8** itself.

The function of the magnets **4**, **5** is to provide a means for preventing the loss of electrons from the ion sources on the negative half-cycle. The respective positive and

negative ion beams withdrawn from the sources will, in most cases, provided for a composite space charged neutralized ion beam, such that it is desirable to prevent the withdrawal of electrons from the ion source that is providing a negative ion beam during the negative half-cycle. The strength of the magnetic field provided by the magnets 4, 5 need not be large, depending upon the charge material that is used in the ion sources. For example, when CsCl is used, the magnetic field strength needs to be only small since very few, if any, electrons are present when this material is ionized due to the complete dissociation thereof when heated to about 1500° centigrade.

The ion sources 1, 2 of FIG. 1 need not be placed one above the other. For example, they may be placed side-by-side as shown in FIG. 2, and the accelerating member 3 modified to provide the ion exit slits thereof in alignment with the exit slits of the ion sources 1, 2. The secondary of transformer 26 is connected to the ion sources 1, 2 of FIG. 2 by leads 29, 30, respectively, and the ground lead 31 is connected to the center of the secondary of transformer 26 and to the member 3, as in FIG. 1. The magnets 4, 5 are positioned as shown in FIG. 2.

In another embodiment of the present invention, as shown in FIG. 3, four ion sources 1, 1', 2, and 2' are provided with the magnets 4, 5 positioned as shown. The ion sources 1 and 1' are connected by lead 29 to one end of the secondary winding of transformer 26, and the ion sources 2 and 2' are connected by lead 30 to the other end of the secondary winding. The accelerating member 3 is not shown in FIG. 3, it being understood that it is provided with four ion exit slits in alignment with the ion exit slits of the ion sources 1, 1', 2, 2'. Such a member 3 or grid is connected to the center of the transformer 26 secondary by the lead 31 in the same manner as in FIG. 1.

The system shown in FIG. 4 is similar to that of FIG. 2, the difference being that the charge material is Cs and the ion sources 1 and 2 provide only positive ions when each is respectively connected to the positive half-cycle of the A.C. high voltage provided by the secondary 49 of transformer 26' over leads 29 and 30 connected to the ion sources 1 and 2, respectively. To provide for space charge neutralization of the respective positive ion beams from the ion sources, there are provided electron guns 37 and 38 associated with the respective ion sources 1 and 2 as shown. Transformer 26' is provided with a low voltage secondary winding 36 and this winding 36 is connected by leads 39 and 40 to the electron guns 37 and 38, respectively. A center tap of winding 36 is grounded, as shown. The means for heating the charge material in each of the systems of FIGS. 2, 3, and 4 is the same as that described for FIG. 1 above.

In operation of the system of FIG. 4, when the ion source 1 is connected to the positive half-cycle of the transformer secondary 49 to provide a positive ion beam therefrom, the electron gun 37 is simultaneous connected to the negative half-cycle of the transformer secondary 36 to provide a beam of electrons therefrom such that the net result is to provide a space charged composite neutralized beam. At the same time, the ion source 2 and electron gun 38 are idle. When the polarities of the secondaries 36 and 49 change, then the ion source 2 and the electron gun 38 are actuated to provide a composite neutralized beam therefrom, while the ion source 1 and the electron gun 37 are then idle. The system of FIG. 4 could be extended to include an additional pair of ion sources connected to the transformer secondary 49 and a pair of electron guns associated with such ion sources and connected to secondary 36 in the same manner as in FIG. 4 to provide for additional neutralized beams.

As mentioned above, a bi-phase generator could be used to replace the high voltage transformer, if desired. In addition, a high-voltage, three-phase generator could also be used. FIG. 5 shows such a system. The rotor 40 of such a three-phase generator is driven by the turbine 18 of FIG. 1 by means of the mechanical coupling 19. Two Y-connected stators 41 and 42 of the generator provide the high voltage connections to the respective ion sources 1, 1', 1'', 2, 2', and 2'' over leads 43, 44, 45, 46, 47, and 48, respectively. The connections to the ion sources are such that each pair of ion sources 1, 2; 1', 2'; and 1'', 2'' provide positive and negative ion beams therefrom, thus providing three space charged neutralized beams from the system of FIG. 5. It should be noted that each of the ion sources of FIG. 5 would be provided with its own individual heater for ionizing the charge material associated therewith. The charge material for the ion sources of FIG. 5 is CsCl, for example. Each heater would have its own individual power supply which can be effected by providing a plurality of transformers such as the transformer 25 of FIG. 1 and connecting such transformers to respective regulators which are in turn connected to an additional generator to be driven by the turbine 18.

The system of FIG. 5 could be modified, if desired, to utilize Cs as the charge material, to provide an electron gun for each of the ion sources, and provide means to energize the electron guns in such a manner as to provide an electron beam from each of the associated guns at the same time the associated ion source is emitting a positive ion beam in the same manner as in the system of FIG. 4 above. With the system of FIG. 5 modified in such a manner, using Cs as the charge material, then such a modified system would sequentially produce only positive ion beams with neutralization of such beams being effected by the sequential energization of the associated electron guns.

It should be understood that the system of FIG. 5 could also be modified, if desired, to use only one Y-connected stator in the generator with the stator leads connected to three ion sources. In such an arrangement, one ion source at the time would provide a positive ion beam while the other two would provide negative ion beams. In some cases, this would be desirable when the respective negative ion beams are individually not as large in magnitude as the positive ion beam, but when taken together they have substantially the same magnitude as the positive ion beam.

The respective pairs of ion sources of FIGS. 1, 2, 3, and 5 could be made concentric, if desired, with the ion emitting areas of the inner and outer ion sources of each pair made substantially equal. However, when a plurality of pairs of ion sources are used, as in FIG. 5 for example, the ion emitting areas would not necessarily have to be substantially equal if the phasing is done carefully. The above-described systems show the use of permanent magnets to provide a magnetic field therefor. It should be understood that, alternatively, the magnetic field may be provided by electromagnetic A.C. coils, if desired, using the same current supplied to the ion sources.

The abovedescribed ion source systems provide a stable, neutralized ion beam or beams suitable for ionic propulsion of space vehicles, such systems requiring only A.C. power for their operation, thus eliminating the need for bulky, heat-producing rectifiers and the necessary radiators to dissipate the heat from such rectifiers.

This invention has been described by way of illustration and not by way of limitation and it should be apparent that the present invention is equally applicable in fields other than those described.

What is claimed is:

1. An improved ion source system for providing a space charged neutralized beam for the ionic propulsion of a space vehicle comprising at least one pair of ion sources, each of said sources including an elongated cavity, a charge material disposed within each of said cavities, an A.C. heater mounted adjacent to said charge material in each cavity for heating and substantially completely ionizing said charge material, a source of A.C. power connected to each of said heaters, and an ion exit slit being

disposed in one wall of each of said cavities; an ion accelerating member disposed in front of both of said ion sources, said member being provided with ion exit slits in alignment with the ion exit slits of said ion sources; a source of A.C. voltage; a high voltage transformer connected to said A.C. voltage; means for connecting one end of the secondary of said transformer to one of said ion sources and for connecting the other end of said transformer secondary to the other ion source; means for connecting a center tap of said transformer secondary to ground and to said ion accelerating member; and a pair of magnets disposed one each at the respective ends of said ion source cavities for providing a magnetic field for electron trapping, whereby the A.C. high voltage provided by said transformer and connected to said ion sources effects production of alternate bursts of negative and positive ions from each of said ion sources such that the positive ion beam from one of the ion sources and the negative ion beam from the other ion source at any given time provide a composite space charged neutralized beam beyond said accelerating member.

2. The ion source system set forth in claim 1, wherein said charge material is CsCl, said heater heating said charge material to a temperature of above 1500° centigrade, and said high voltage transformer providing an acceleration voltage between said ion source enclosures and said accelerating member of about 30 kv.

3. The ion source system set forth in claim 1, wherein said ion source cavities are positioned one above the other.

4. The ion source system set forth in claim 1, wherein said ion source cavities are positioned in side-by-side relation.

5. The ion source system set forth in claim 4, wherein a second pair of ion sources are provided and positioned in side-by-side relation to each other and below the first pair of ion sources, means for connecting one diagonal pair of said ion sources to one side of said transformer secondary and for connecting the other diagonal pair of said ion sources to the other side of said transformer secondary, said accelerating member being provided with

a second pair of ion exit slits in alignment with the ion exit slits of said second pair of ion sources, said second pair of ion sources also being provided with respective charge materials and heaters therefor, and said source of A.C. power being connected to the heaters of said second pair of ion sources.

6. The ion source system set forth in claim 1, wherein said charge material is Cs, said ion sources each providing only a positive ion beam when each is connected to the positive half-cycle of said high voltage transformer secondary, said system further including an electron gun associated with each of said ion sources, said high voltage transformer being provided with a low voltage secondary and said low voltage secondary being connected at its respective ends to said electron guns such that when one of said ion sources is emitting a positive ion beam the electron gun associated therewith is providing an electron beam resulting in a composite neutralized beam.

7. The ion source system set forth in claim 1, wherein said ion sources are arranged in concentric relation.

8. The ion source system set forth in claim 1, wherein two additional pairs of ion sources are provided, and a high voltage multi-phase generator is substituted for said high voltage transformer including means for driving said generator, said generator being provided with a pair of Y-connected stators, and means for connecting respective stator leads of said stators to respective ones of said ion sources thereby providing a plurality of space charged neutralized beams.

References Cited by the Examiner

UNITED STATES PATENTS

3,052,088	9/1962	Davis et al.	60—202
3,116,433	12/1963	Yeates	313—63
3,177,654	4/1965	Gradecak	60—202
3,210,926	10/1965	Forbes et al.	60—202

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