NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF:

October 16, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,304,718

Corporate Source : Hughes Aircraft Company

Supplementary
Corporate Source :

NASA Patent Case No.: XNP-02839

Please note that this patent covers an invention made by an employee of a NASA contractor. Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of. . . ."

G Parker

Gayle Parker

Enclosure:
Copy of Patent

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Feb. 21, 1967 JAMES E. WEBB 3,304,718

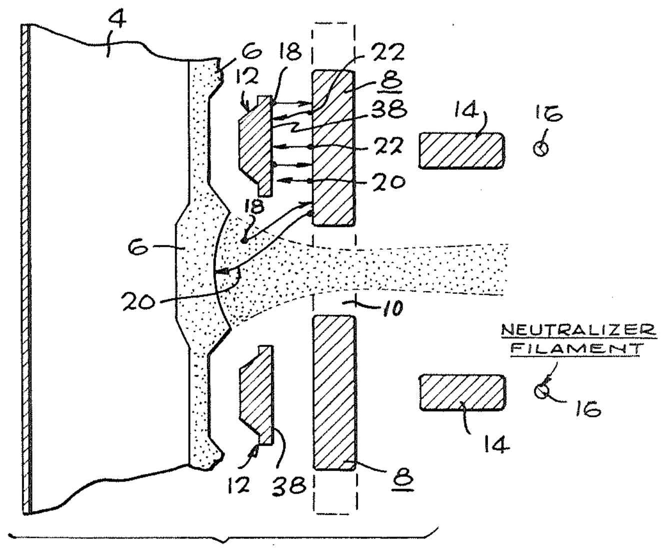
ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

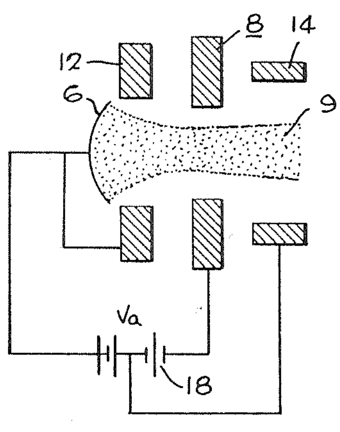
DOUBLE OPTIC SYSTEM FOR ION ENGINE

Filed Aug. 4, 1965 2 Sheets-Sheet 1

Fig. 1

PRIOR ART





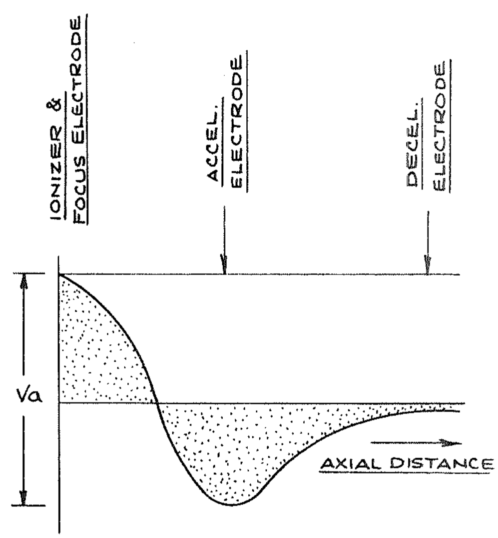


Fig. 2

Fig. 3

ROBERT L. ZIMMERMAN
INVENTOR.

BY [signature]

Howard B. Scheckman

ATTORNEYS

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Fig. 4

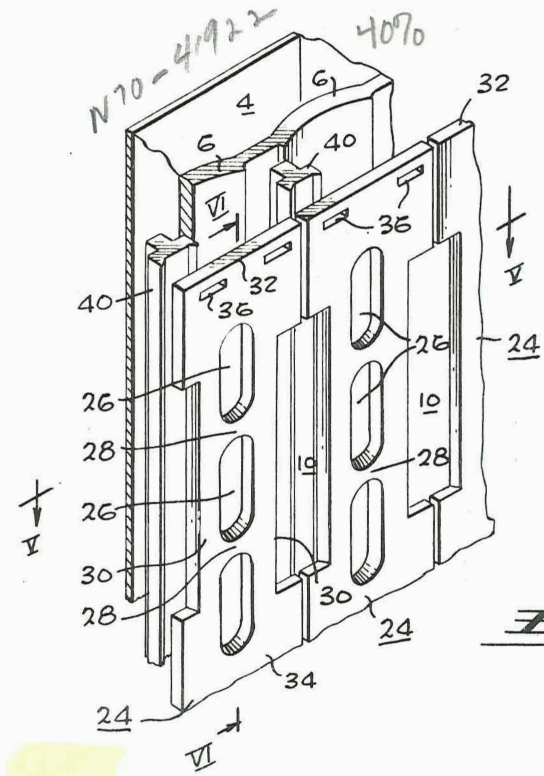


Fig. 6

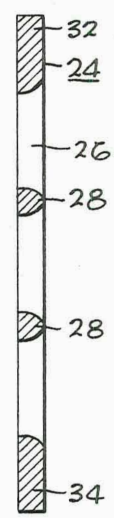
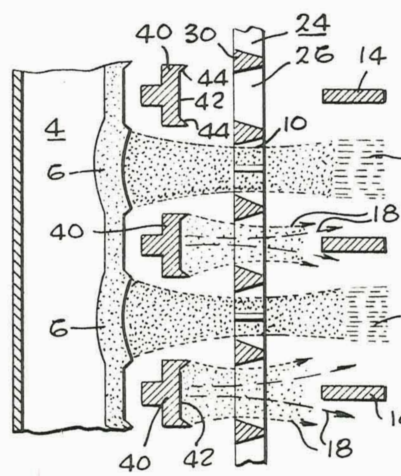


Fig. 5



INV[illegible]R.
ROBERT L. ZI[illegible]MAN

BY G. T. McCoy
Howard B. Scheckman
ATTORNEYS

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United States Patent Office

3,304,718
Patented Feb. 21, 1967

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3,304,718
DOUBLE OPTIC SYSTEM FOR ION ENGINE

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Robert L. Zimmerman, Northridge, Calif.

Filed Aug. 4, 1965, Ser. No. 477,333
7 Claims. (Cl. 60—202)

This invention relates to ion engines and more specifically to an improved construction of the electrodes of such engines to increase their lifetime.

Ion engines are presently being designed for use on space vehicles to provide propulsion for extended trips into space. The desired lifetime of such ion engines is between 10,000 and 30,000 hours (3 to 10 years). An engine operating with this extensive lifetime must have a very high reliability of operation. Minor problems that are normally not important where there is only a short life span can present serious problems over an extended time period.

As background, ion engines of the type that use a low ionization expellant, such as cesium, are constructed with a number of electrode elements forming an optic system. These include an emitter that emits a cesium ion stream, a focus electrode to focus the ions issuing from the emitter, an accelerator (accel) electrode to accelerate the ions, a decelerator (decel) electrode that brings the speed down to the right velocity, and a neutralizer filament to return electrons to the ion stream to neutralize it.

One of the major problems associated with the above type of ion engine is ion bombardment of the accel electrode. This bombardment has been found to be one of the principal and ultimate limitations on ion engine life.

Ion bombardment results when some of the expellant includes atoms that become ionized in an area where the various electrical fields do not have sufficient influence on them to propel them out of the engine. These atoms once ionized, are known as spurious ions. These spurious ions present a number of problems.

One problem is that they shorten the life of the accel electrode. Being positively charged, the spurious ions are drawn to the accel electrode surface that has a high negative potential. The ions impinge on the accel electrode surface and cause sputtering of accel electrode material and erode the electrode. Most spurious ions are formed on, and come from the focus electrode where expellant atoms tend to condense. In addition, the accel electrode helps in the formation of these spurious ions on the focus electrode. It generates electrons that impinge on the focus electrode and heat this element. The heat aids in the formation of more spurious ions.

Another problem that results from spurious ions is that the material sputtered off of the accel electrode tends to clog the ionizer surface to interfere with operation of this element.

Another problem is that the spurious ions decrease the efficiency of the engine. These spurious ions do not add any thrust to the ion engine.

Ion bombardment is therefore an extremely serious problem. It follows that if the adverse effects of ion bombardment on the accel electrode can be decreased, this in turn will greatly extend the lift span of the ion engine. It also follows that if these spurious ions can be used to produce thrust, then the efficiency of the ion engine will be increased.

In view of the above, it is therefore a principal object of this invention to increase the life span of an ion engine over prior art engines.

Another object of this invention is to increase the efficiency of an ion engine.

Essentially, this invention teaches how to construct the

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accel and focus electrodes of an ion engine, so that the ion bombardment does not adversely affect the life or efficiency of the ion engine.

A portion of the accel electrode, facing the focus electrode, is removed. This provides a passage through the accel electrode for the spurious ions. This also creates, in effect, a way of permitting these spurious ions to add their thrust to the main propulsion system.

This construction does not prevent the formation of the spurious ions, but acts as a second optic system to direct the ions so they pass through the accel electrode without impinging on it. Spurious ions generated on the focus electrode are thus made to produce thrust to increase the efficiency of the engine instead of shortening the engine's life.

Also in line with the above, the focus electrode's surface is provided with a concave shape so as to direct the spurious ions toward the opening in the accel electrode, or into the main ion stream so the ions do not tend to strike the accel electrode.

Other objects and advantages will appear from the specification and claims taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a view of a prior art ion engine showing the general optic system;

FIG. 2 is a schematic showing of the various voltage connections of the electrodes of the ion engine;

FIG. 3 is a graph showing the relative potential on the various electrodes of the ion engine;

FIG. 4 is an isometric enlarged view of a portion of an ion engine of the present invention showing the ionizers, focus, and accel electrodes;

FIG. 5 is a cross section of FIG. 4 taken in the direction of arrows V—V, more clearly showing the openings in the accel electrodes; and

FIG. 6 is a sectional view of FIG. 4 taken in the direction of arrows VI—VI showing a different sectional view of the accel electrode.

Referring to FIG. 1, there is shown a cross section of a portion of a prior are engine **2** of strip design as background, to show how the teachings of this invention can be applied to an engine of this type.

The ion engine is provided with a manifold **4** that contains a propellant material to be ionized. This may be cesium, for example. The propellant material is ionized by an ionizer **6**. Where cesium is used, the ionizer may be made of tungsten.

Positioned on each side of each ionizer **6** is an accel electrode **8**. The accel electrode functions to accelerate the main stream of ions **9** through an opening **10** and propel the ions out of the engine.

Also, positioned on each side of each ionizer **6** is a focus electrode **12**. The focus electrode is spaced between accel electrode **8** and ionizer **6**. The focus electrode functions to control the ionizer current density distribution and the trajectories of the ions to avoid direct interception of the main ion stream with the accel electrode. A decel electrode **14** is also positioned on each side of the ionizer and operates to bring down the velocity of the ions and acts like a screen grid in a vacuum tube. It shields the accel electrode so the ions do not "see" the highly negative field of the accel electrode. A neutralizer filament **16** is also positioned on each side of ionizer **6** and returns electrons to the ion stream to neutralize it.

In an ion engine of strip design, the various electrode elements are made in elongated strip form (see FIG. 4). Strip ion engines have been chosen as a basic design configuration because they can be made very compact and can provide higher thrust than other types. Their ionizers can be positioned in very nearly contiguous relation so they can be formed into a very compact structure. Also, a large area ionizer can be obtained by constructing a number of linear contiguous ionizer strips to form a rectangular engine. This, in turn, can become the basis for a compact high thrust engine for space propulsions.

Referring to FIG. 2, there is shown a schematic representation of the voltage connections of the various electrodes of the ion engine of FIG. 1. Ionizer 6 and focus electrode 12 are both connected to the positive terminal of voltage source V*a*. Accel electrode 8 is connected to the negative terminal of voltage source V*a*, and decel electrode 14 is connected to the center tap of the voltage source.

FIG. 3 shows graphically the relative voltages of the elements and their axial distance from the ionizer. The emitter and focus electrodes have a high positive voltage. The accel electrode has a high negative voltage relative to the emitter and focus electrodes, while the decel electrode is close to ground potential relative to the emitter and accel electrodes.

Ion bombardment of the accel electrode is shown in FIG. 1. During operation of this engine stray atoms of expellant arrive on hot focus electrode 12 and become ionized. Also, some expellant atoms become ionized in the main ion stream due to collision with ions. Once ionized, these positive ions 18, from the focus electrode and main ion stream, accelerate toward the highly negative accel electrode surface wherein their energy is dissipated and results in sputtered accelerator material 20. Also, negative electrons 22 are drawn from the accel electrode to the focus electrode by its high positive voltage. These impinge on this element to increase its temperature and enhance the formation of more ions.

Some of the sputtered accel electrode material 20 is also deposited onto the ionized as a secondary action. This results in a coating on the ionizer than can completely clog the pores of the ionizer and inhibit the action of this member. The sputtered accel material also condenses on the focus electrode and continues to provide an ionization surface to thereby continue the cycle of destruction. Erosion of the accel electrode takes place generally in a narrow region immediately above the focus electrode.

Referring to FIGS. 4, 5 and 6, there is shown an ion engine using the construction of this invention. Similar elements referred to previously have been provided with the same numbers. This ion engine is like the engine shown in FIG. 1 having the same voltage connections and relative potentials as shown in FIGS. 2 and 3. However, it has been provided with an accel electrode 24 that has been made slotted to provide a series of secondary apertures or openings 26 in its central section and a concave focus electrode as will be explained below.

Referring to FIG. 5, opening 26 in the accel electrode will permit spurious ions 18 to pass through opening 26 rather than impinge on the electrode.

Accel electrode 24, when viewed in plan from the top, resembles a capital "I" with openings 26 in its central portion separated by cross pieces 28 (FIG. 6). The ends, or upper and lower portions 32, 34 of the "I" contain openings 36 that receive conductors (not shown) that are connected to the voltage source V*a*. Side 30 of one accel electrode 24 cooperates with the adjacent side 30 of an adjacent accel electrode to form the main aperture or opening 10 through which the main ion stream passes.

Gross pieces 28 between openings 26 are merely provided for strength because sides 30, 30 (FIG. 5) of the accel electrode are quite thin due to the open portions 26. Where the sides are of sufficient strength, reinforcing cross pieces 28 can be omitted.

Referring to FIG. 5, accel electrode's walls 30 are substantially triangular in cross section with the base facing the focus electrode. The entrance to opening 26 is narrower than the exit of the opening. This is to provide the least material in the path of spurious ions 18 so as to decrease the likelihood of a spurious ion impinging on the accel electrode.

Referring to FIG. 1, it will be noted that focus electrode

12 has a flat surface 38. In the new construction in FIG. 5, focus electrode 40 has been provided with a surface 42 that has been made concave with side tips 44, 44. The concave surface, in cooperation with the electrical field, acts to guide ions from the focus electrode surface 42 toward opening 26 in accel electrode 24. If an ion is formed on the vertical side of the focus electrode, it will be guided toward main ion stream 9 so there will be less likelihood of the ions impinging on the accel electrode. This helps to further decrease ion bombardment, and thereby increase the life of the ion engine.

Since the accel electrode now has openings 26 in it, it would appear that the spurious ions would now impinge on the decel electrode 14 positioned behind it. However, this is not a problem. This is because decel electrode 14 has a very weak potential, as shown in FIG. 3, so it does not attract ions. Also, the path of the ions due to the electrical field is such that they miss the decel electrode.

Operation: Referring to FIG. 5, ions issue in a stream 9 from emitter 6 and are accelerated by the high negative voltage on accel electrode 24. When the main ion stream passes between the two focus electrodes 40, 40, the ions are repelled by the high positive voltage on the focus electrodes. This causes the ions stream to narrow so as to miss the accel electrodes 24 and pass through opening 10 formed between two adjacent accel electrodes 24. The stream then moves past decel electrodes 14 that functions to bring the ions speed down to the right velocity. The stream then passes neutralizer filament 16 that add electrons back to the stream to neutralize it.

Spurious ions 18 from concave focus electrode 40 and from main stream are propelled through openings 26 in accel electrode 24. These ions add their thrust to that of the main ion stream, thus making the engine more efficient.

Erosion of the accel electrode 24 has been decreased because the number of spurious ions that impinge on accel electrode 24 have been greatly decreased. Also, with the central openings 26 in the accel electrode, a large area has been eliminated from which electrons 22 (FIG. 1) had originated and travelled to the focus electrode to heat this element. Openings 26 also decrease clogging caused by sputtering of accel electrode material 20 onto ionizer 6.

The new construction provides two optic systems. One system controls the main ion stream guiding it through openings 10 formed in adjacent accel electrodes 24, 24. The other optic system guides spurious ions 18 through openings 26 in accel electrode 24. With this construction, the life span of the ion engine has been greatly increased, as well as its operating efficiency.

It will be noted that while specific configurations, as well as types of material, are set forth that this is by way of example only. For example, while the strip ion engine is shown as having a rectangular shape, other shapes, such as annular, can be used. It will be apparent to one skilled in the art that variations can be made without departing from the teachings of this invention, and that the invention includes such other forms or modifications as are embraced by the scope of the appended claims.

What is claimed is:

1. In an ion engine, the combination comprising: a source of ionizable propellant, an ionizing means for receiving said propellant and producing a stream of ions, a focus electrode downstream of said ionizing means and an accelerator electrode downstream of said focus electrode, said accelerator electrode having a main aperture for receiving said ion stream and a secondary aperture for receiving spurious ions originating from said focus electrode.

2. A device, as set forth in claim 1, wherein said focus electrode is made with a concave portion facing said secondary aperture in said accelerator electrode, to direct spurious ions towards that secondary aperture.

3. A device, as set forth in claim 1, wherein said accel-

erator electrode is constructed with said secondary aperture facing said focus electrode.

4. A device, as set forth in claim 1, wherein said secondary aperture in said accelerator electrode is constructed with its entrance narrower than its exit so as to decrease the liklihood of a spurious ion impinging on said accelerator electrode during passage through said accelerator electrode.

5. A device, as set forth in claim 1, wherein said focus electrode is constructed to direct ions originating from it, towards said secondary aperture in said accelerator electrode.

6. A device, as set forth in claim 5, wherein said focus electrode is made concave.

7. In an ion engine, the combination comprising: a source of ionizable propellant, an ionizing means for receiving said propellant and producing a stream of ions, a focus electrode downstream of said ionizing means and an accelerator electrode downstream of said focus electrode, said accelerator electrode having a main aperture

for receiving said ion stream and a secondary longitudinal elongated aperture aligned with said focus electrode, for receiving spurious ions originating from said focus electrode.

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CARLTON R. CROYLE, *Primary Examiner.*