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

REPLY TO
ATTN OF: GP

April 5, 1971

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. : 3,412,559

Corporate Source : Electro-Optical Systems, Inc.

Supplementary Corporate Source :

NASA Patent Case No.: XNP-06942

Gayle Parker

Enclosure:
Copy of Patent

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NASA-HQ

Nov. 26, 1968 G. SOHL 3,412,559

ION ENGINE CASING CONSTRUCTION AND METHOD OF MAKING SAME

Filed July 6, 1966 4 Sheets-Sheet 1

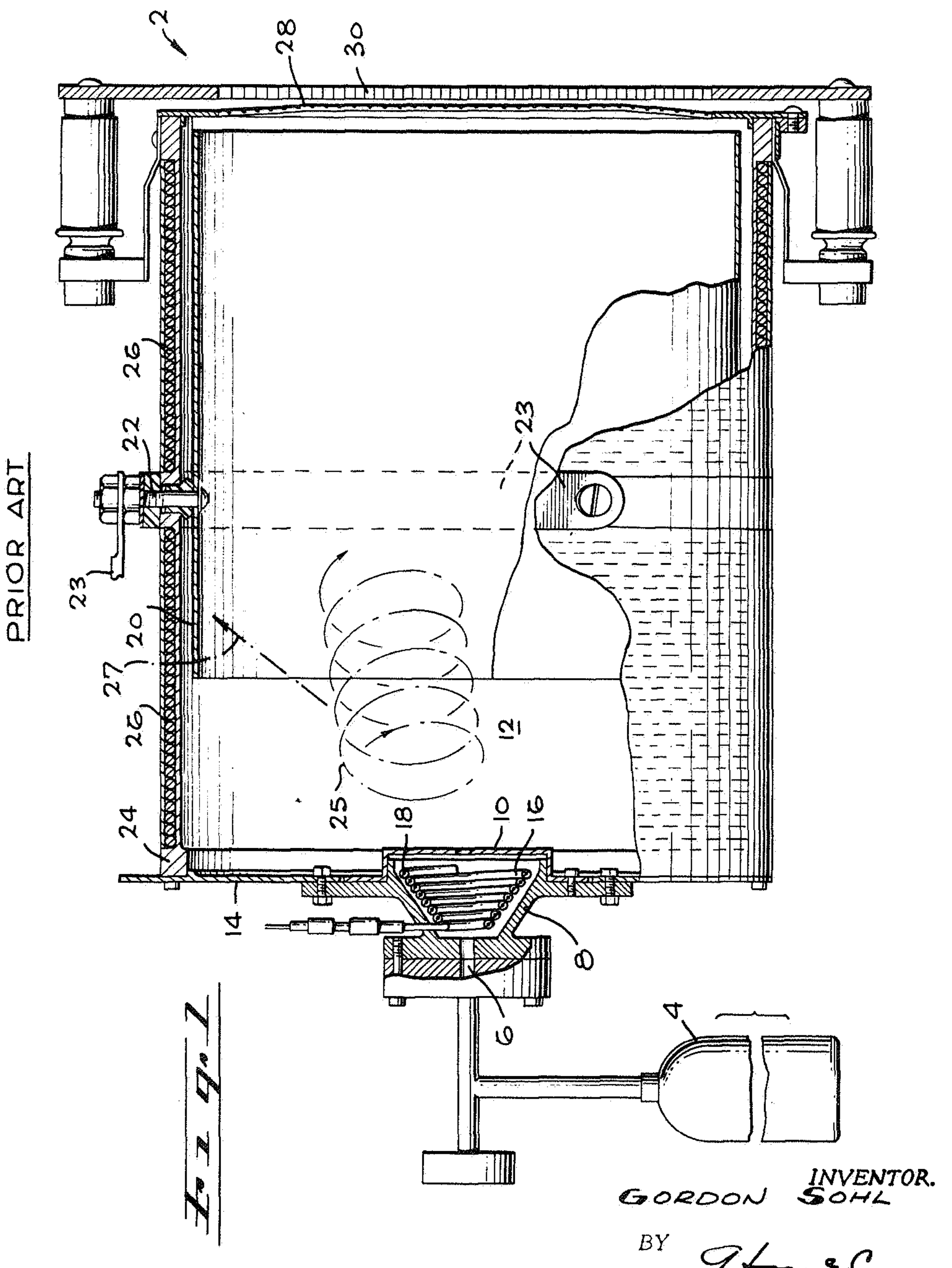

Fig. 1

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PRIOR ART

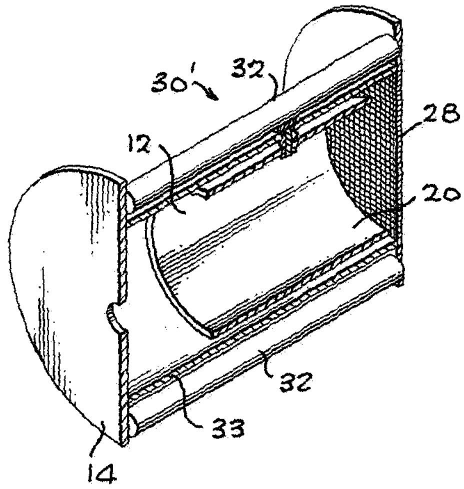
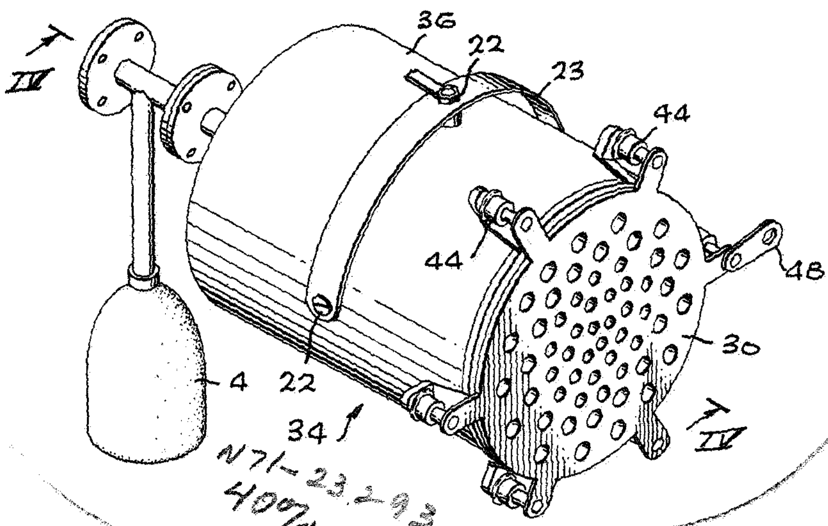


Fig. 2

Fig. 3



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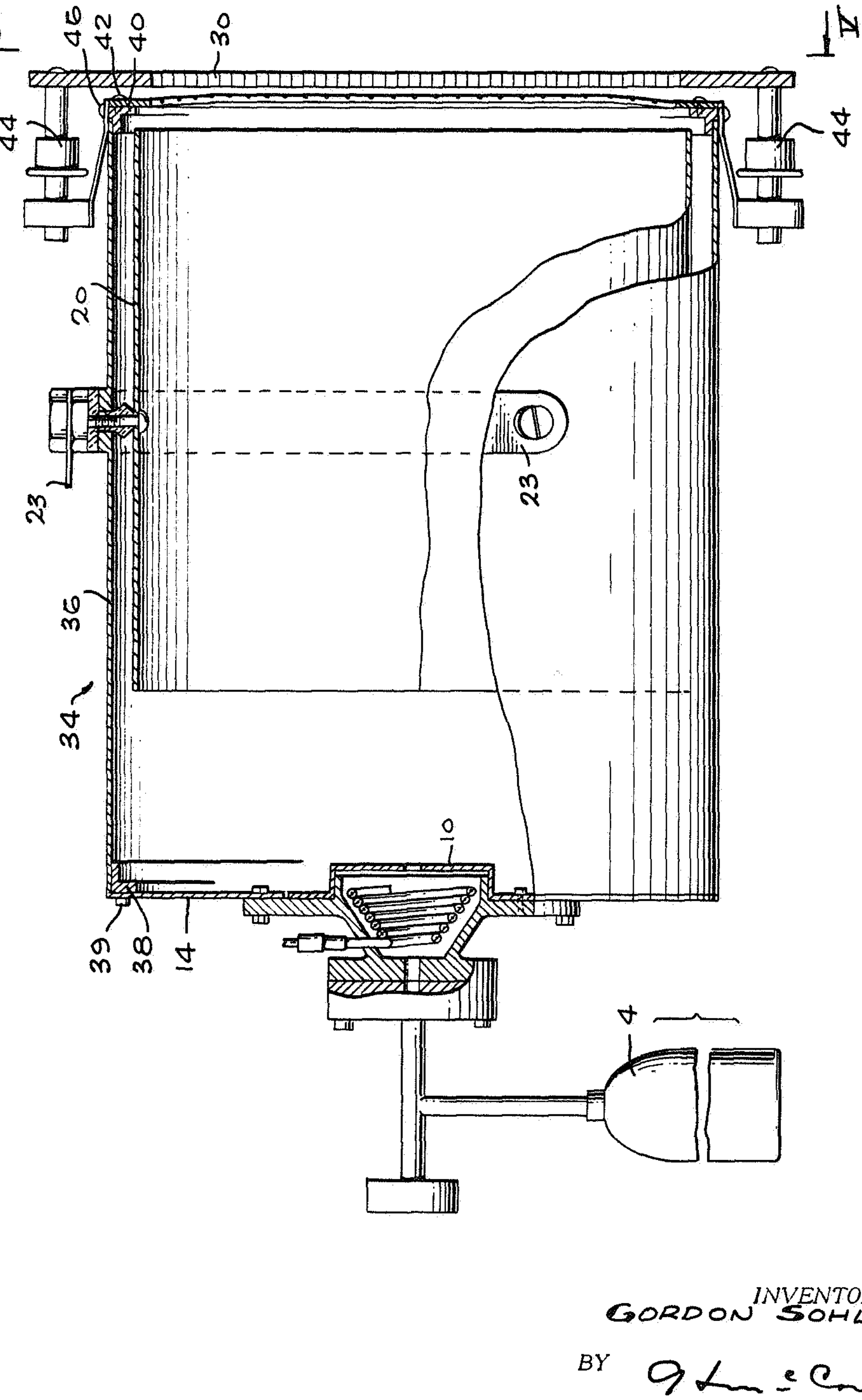

Fig. 4

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Fig. 5

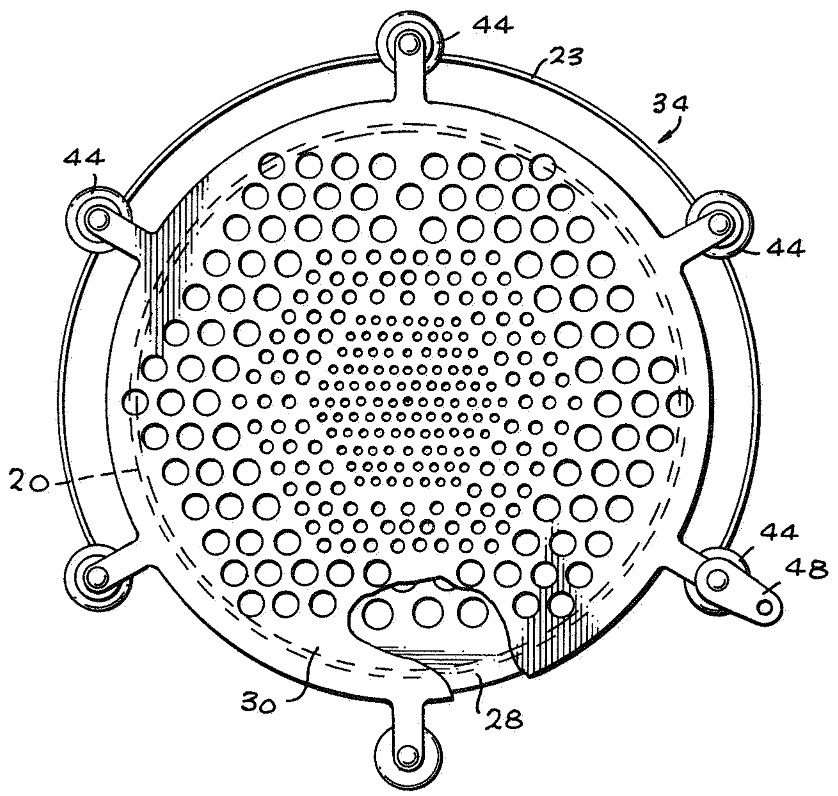
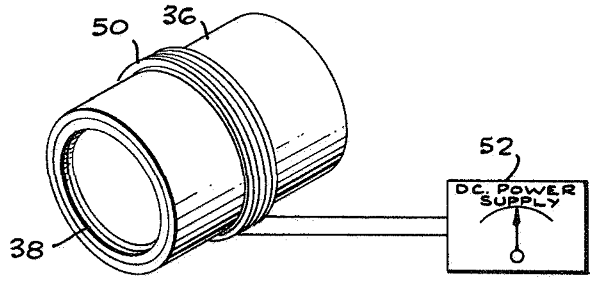


Fig. 6



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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,412,559 November 26, 1968

James E. Webb Administrator of The National Aeronautics and Space Administration

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading to the drawings, line 1, Sheets 1 to 4, "G. SOHL" should read -- JAMES E. WEBB, ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION --. In the heading to the printed specification, line 4, "Gordon Sohl, 84 S. Craig Ave., Pasadena, Calif. 91107" should read -- James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Gordon Sohl --.

Signed and sealed this 24th day of March 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents

United States Patent Office

3,412,559
Patented Nov. 26, 1968

3,412,559

ION ENGINE CASING CONSTRUCTION AND METHOD OF MAKING SAME

Gordon Sohl, 84 S. Craig Ave., Pasadena, Calif. 91107

Filed July 6, 1966, Ser. No. 563,651
10 Claims. (Cl. 60—202)

ABSTRACT OF THE DISCLOSURE

An improved ion engine, the casing of which is permanently magnetized to generate a desired magnetic field.

Origin of the invention

The invention described here in was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Statute 435; 42 U.S.C. 2457).

Background of the invention

This invention relates to ion engines, and more particularly to an improved electron bombardment ion engine that is more efficient, weighs less, and is less complicated in construction than previous engines of this type.

Ion engines are being extensively investigated in the field of propulsion for spacecraft for long space missions. An ion engine for the above type of mission must be able to operate for very long periods of time unattended. As an example, it is contemplated that an ion engine will have to operate 10,000 to 20,000 hours on some of these space missions.

Ion engines, of course, are not new. An example of one type of ion engine may be seen in the U.S. Government Publication, NAS SP–22, titled "Electric Propulsion for Spacecraft," dated December 1962, page 28, FIG. 48(*c*)–5. This publication is available from the Superintendent of Documents.

The ion engine shown in the above publication, and as will be more fully explained later on, operates to cause an electron to collide with an expellant atom. The collision results in the formation of two electrons, and an ion that is accelerated and used for thrust. To increase the probability of an electron colliding with an atom, a field coil is placed around the ion engine's casing and is used to create a magnetic field to influence the path of travel of the electrons. The magnetic field causes the electrons to travel in a spiral path to increase the likelihood of collision with an atom. If the magnetic field were omitted, the electron would be drawn generally in a straight-line path to the ion engine's positive anode, and the chances of its colliding with an atom would be greatly diminished.

Another example of an ion engine, that will also be more fully described hereinafter, is shown in the above publication on page 28, FIG. 48(*c*)–6. This figure shows an ion engine having a plurality of permanent bar magnets around the outer casing of the engine in the place of the magnetic field coil. Bar magnets eliminate the power formerly required by the field coil. They also reduce the need for a separate power supply previously required to energize the field coil, thus further simplifying the engine.

While the engine with bar magnets is an improvement over the engine with a field coil, both engines weigh approximately the same amount. This is because the bar magnets themselves add weight to the engine.

With the above in mind, it is apparent that an ion engine that can be made lighter than ion engines of the field coil, or bar magnet type, and still deliver the same amount of thrust, would provide a distinct advantage for a successful space mission. Along the same line, it would

be an even greater advantage in space flight if the engine could also be made more efficient, and less complicated structurally.

Summary of the invention

An ion engine that is constructed as taught by this invention, as discussed hereinafter, is more efficient than prior art types. It is capable of providing the same or greater thrust than previous ion engines of the above type. It is less complicated structurally. And, it is lighter in weight.

The above is accomplished by eliminating the bar magnets and field coil of the ion engine entirely. This invention teaches using the casing of the ion engine to create the magnetic field.

According to the teaching of this invention, the outer casing of the ion engine is made out of a magnetizable material. It is then selectively magnetized to create a permanent magnetic field that provides increased efficiency for the ion engine. That is, one circumferential section of the casing can be made with a weaker or stronger magnetic field relative to another circumferential section of the casing to vary the magnetic field axially along the length of the casing.

The casing is easily fabricated by rolling magnetic sheet stock into a cylinder. Then the casing is placed within a magnetizing coil and magnetized. The magnetizing coil is connected to a DC power supply whose current can be varied or reversed so the strength of the magnetic field can be adjusted to vary the magnetization in selected portions of the casing. Thus a tailer-made magnetic field can be created having any selected characteristics desired.

The invention also teaches a preferred way of magnetizing the casing so as to create the desired magnetic field. The casing is magnetized to its highest magnetization and then the portions of the surface, where weaker magnetic fields are desired, are slightly demagnetized. This provides very accurate control over the magnetic field.

With the above in mind, it is therefore an object of this invention to construct an ion engine that is more efficient than prior art types.

Another object of this invention is to provide an ion engine that can be made lighter than prior art types, yet will yield the same or a greater amount of thrust.

It is another object of this invention to provide an ion engine that is less complicated structurally than prior art types.

Another object of this invention is to teach a preferred method of magnetizing an ion engine casing to provide accurate control of the magnetic field being created.

Brief description of the drawings

Other objects and advantages will appear from the following description considered in conjunction with the accompanying drawings:

FIG. 1 is a sectional view of a prior art ion engine utilizing a field coil;

FIG. 2 shows a simplified portion of prior art ion engine that employs bar magnets;

FIG. 3 is an overall exterior view of the ion engine of this invention;

FIG. 4 is a sectional view of FIG. 3 taken in the direction of arrows IV–IV;

FIG. 5 is an end view of FIG. 4 taken in the direction of arrows V—V; and

FIG. 6 shows how the chamber of the ion engine can be magnetized.

Preferred embodiment of the invention

To help explain the invention, a prior art field coil ion engine and a prior art bar magnet ion engine will first be briefly described. These will help to point out applicant's invention over the prior art.

Referring to FIG. 1, there is shown a sectional view of a prior art electron bombardment ion engine **2** of the field coil type. Essentially the engine operates to ionize an expellant material, such as cesium vapor (not shown) and to eject the ions out of the engine, using a high negative voltage, so as to provide thrust. Generally the cesium vapor is admitted from reservoir **4** through opening **6** in cathode **8** through orifice plate **10** to ionization chamber **12** at a controlled rate. Cathode **8** is supported by a cathode plate **14**. The cathode includes a tubular emitter **16** made, for example, of tantalum, that emits electrons when heated. A heater **18** is imbedded in and is coaxial with the emitter to heat it. The electrons and vapor enter ionization chamber **12** through orifice plate **10**.

The electrons are attracted to the peripheral cylindrical anode **20**. Anode **20** is carried by an anode support comprising feed-through bolts **22** that are connected to cylindrical casing **24**. Anode electrical connections are made through strap **23** connected to bolts **22**.

A field coil **26** surrounds casing **24** and creates an axial magnetic field that acts on the electrons to give them a spiral path **25** to facilitate collisions between the electrons and atoms so as to create ions as explained previously. For comparison purposes, the path of an electron, if the magnetic field was omitted, is shown by dotted lines **27**.

The ions are extracted by a high potential difference pressed across the perforated plate-shaped screen electrode **28** and perforated plate-shaped accelerator electrode **30** to provide thrust.

With respect to this type of engine, it is emphasized that casing **24** is surrounded by field coil **26**. One of the principal power losses in this type of engine is the energy that is used to energize field coil **26** to maintain the magnetic field.

An ion engine employing a field coil has just been described. An ion engine utilizing bar magnets will now be described.

Referring now to FIG. 2, a simplified illustration of a second type of prior art ion engine **30'** is shown. Like parts are similarly numbered. This type is like the type shown in FIG. 1 except that a plurality of bar magnets **32** have been placed around outer casing **33** and are used in place of field coil **26** of the prior art engine shown in FIG. 1. To accommodate the bar magnets, cathode plate **14** and screen electrode plate **28** have been enlarged in diameter. Magnets **32** induce a magnetic field throughout ionization chamber **12**.

The advantages in the use of bar magnets **32**, as mentioned previously, is that they eliminate the power required by the previous field coil. They also reduce the need for a separate power supply to energize the field coil.

Having the above two prior art ion engines in mind, the ion engine of the present invention will be described.

Referring to FIGS. 3, 4, and 5, there is shown an exterior view, a sectional view and an end view of ion engine **34** of this invention. This ion engine is generally similar to the prior art engines except that it does not contain a field coil or bar magnets. Like parts have been similarly numbered and will not be described again. Outer casing **36** (that corresponds to outer casings **24** and **33** of the prior art engines) has been magnetized to replace the magnetic field formerly created by the field coil and bar magnets.

Outer casing **36** is of cylindrical shape. At one end (to the left in FIG. 4), is connected an iron rim **38**. The rim acts as a pole piece, and is used as a support to which cathode plate **14** is connected by screws **39**.

Casting **36** has a second iron rim **40** connected to its other end that also acts as a pole piece and as a support. Screen electrode **28** is connected to rim **40** by screws **42**. Accelerator electrode **30** is carried by insulator assemblies **44** and is in turn connected to rim **40** by screws **46**. Referring to FIG. 5, accelerator electrode **30** is provided with a terminal **48** for electrical connections.

It will be noted, in comparing the prior art ion engines, illustrated in FIGS. 1 and 2 of the invention, that field coil **26** in the ion engine, shown in FIG. 1, as well as bar magnets **32** and enlarged plates **14, 28** of the ion engine shown in FIG. 2, have been eliminated. The present ion engine is constructed so that outer casing **36** alone produces the magnetic field.

One example of the construction of casing **36** follows: A permanent magnetic casing with a coercive force of about 20 oersteds was needed when constructing the ion engine. A sheet stock of magnetizable material (such as Vicalloy) was used for the ion engine casing. According to calculations it was determined that the casing could be made to a design minimum thickness of .007 inch. However, for convenience, the thickness actually used was .016 inch.

The casing was rolled from the magnetizable sheet stock into cylindrical form and electron beam welded to the iron rims. The casing was then heat-treated to develop the magnetic properties, and then magnetized.

Referring to FIG. 6, there is shown one method of magnetizing ion engine casing **36**. Only rim **38** can be seen in this figure, although rim **40** is connected to the other end. A charging coil **50**, connected to a DC supply **52**, is used. Any DC supply can be used whose current and polarity can be varied. This is deemed desirable because considerable difficulty was initially encountered in properly magnetizing the engine casing. This difficulty was caused by iron rims **38** and **40** distorting the coil's charging field. The iron rims ended up with significantly higher magnetization than the center of the casing. It was discovered that the results desired could be obtained by charging the center of the casing to the point where it was properly magnetized and then reversing the field to demagnetize the ends slightly.

A magnetic field was selectively created within the engine casing that was slightly weaker at the cathode end, increased in strength to the center and then decreased in strength axially from the center toward the screen electrode by about 15%. A field of this nature, with a weaker field at the screen electrode end, tends to exert a down stream force on electrons; this sets up a potential gradient that accelerates ions toward the screen electrode. The ends result of the electrons colliding with the atoms, and also moving toward the screen electrode, is for the electrons to essentially sweep the ions toward the screen and eccelerator electrodes.

An engine, constructed as above, has operated with increased performance due to the magnetic field configuration. Operation at high mass utilization efficiency, that is, number of ions accelerated to obtain thrust, was increased, and this was possible with a lower degree of arc power required (arc power = cathode to anode voltage X anode current). Much greater efficiency was thus obtained with reduced power.

Additionally, it has been found that the use of the magnetized casing **36**, as taught by the invention, eliminates various distortions of the megnetic field that were present in the magnetic field created by field coil **26** and bar magnets **32**, so the magnetic field created is now more efficient.

An idea of the weight saving of the engine of this invention, which construction was previously described, compared to a bar magnet ion engine, may be helpful. The bar magnet engine had approximately the same diameter outer casing as the engine of this invention and weighed approximately 4.3 pounds. The engine of this invention weighed approximately 2.45 pounds, a weight reduction of almost half. Additionally, even further weight reduction could have been made by using the calculated design minimum for the material of the magnetic casing.

It will be obvious to those skilled in the art that the magnetic field strength of casing 36 can be made to diverge or converge toward the ends, or varied by adjusting the magnetization, or by varying the thickness of the casing along its length. Thus a magnetic field can be created having exactly the characteristics desired. It will be equally obvious to those skilled in the art that the casing can be fabricated with the rings 38 and 40 unitary, and the casing can be fabricated by other methods, such as casting, for example.

In summary, it will be seen that making the cylindrical casing a permanent magnet provides a number of advantages: the ion engine is lighter because the field coil and bar magnets used in previous ion engines have been eliminated. The ion engine is more efficient because the magnetic field can be tailor-made to provide the most efficient configuration that acts on the electrons. Additionally, the engine is more simple structurally, because not only have the field coil and bar magnets been eliminated, but the accompanying supporting structure has also been eliminated.

While it is stated that the ion engine is to be used for propulsion of a space vehicle, this is used by way of illustration only; other uses of the ion engine will be apparent to those skilled in the art, and although one embodiment of the invention has been described, it will be apparent to those skilled in the art that various other modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

What is claimed is:

1. In an ion engine, of the electron bombardment type having an accelerator electrode, the improvement comprising:

an outer casing for said ion engine that is a permanent magnet.

2. A device, as set forth in claim 1, wherein said outer casing is cylindrical.

3. A device, as set forth in claim 2, wherein said cylindrical permanent magnet casing includes a pole piece at each end of said casing.

4. A device, as set forth in claim 1, wherein said outer permanent magnet casing is constructed with a magnetic field that decreases in strength toward the end of said casing adjacent said accelerator electrode.

5. In an ion engine, of the electron bombardment type having an accelerator electrode, the improvement comprising:

an outer casing for said ion engine that is a hollow cylindrical permanent magnet, said permanent magnet having a magnetic field that varies axially from a high near the center of the casing to a low at the accelerator electrode end of said casing.

6. A device, as set forth in claim 5, wherein said other end of said outer casing is provided with a magnetic field that is also weaker than the magnetic field near the center of said casing.

7. In an ion engine, the combination comprising:

an outer cylindrical casing, said casing being a permanent magnet;

a cylindrical anode, coaxial with and supported within said casing;

a cathode, including an electron emitter, supported at one end of said casing and positioned to emit electrons to the interior of said anode;

structure to introduce an ionizable expellent vapor into the interior of said anode; and

screen and accelerator electrodes supported from one end of said casing.

8. A device, as set forth in claim 7, wherein said cylindrical casing is constructed with a magnetic field that decreases in strength from the center toward the ends of said casing.

9. In the method of making the outer casing of an ion engine, of the electron bombardment type that includes an accelerator electrode, the steps comprising:

making the outer casing of said ion engine of magnetizable material,

magnetizing the center of said casing to the point where it is properly magnetized, and then

slightly demagnetizing the end of said casing adjacent said accelerator electrode.

10. A method, as set forth in claim 9, including the step of slightly demagnetizing the other end of said casing, but a less amount than the accelerator end of said casing.

References Cited

UNITED STATES PATENTS

2,460,684	2/1949	Farrow	317—157.5
3,159,967	12/1964	Webb	60—202
3,162,398	12/1964	Clanser et al.	60—202
3,171,081	2/1965	Garwood	313—7
3,238,715	3/1966	Reader et al.	60—202
3,273,336	9/1966	Kidwell	60—202

CARLTON R. CROYLE, *Primary Examiner.*