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[54] **PLASMA ARC THRUSTOR**
11 Claims, 2 Drawing Figs.

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[51] **Int. Cl.** **F02k 7/08**
[50] **Field of Search** ..... 60/202, 203; 219/121 D; 313/30, 40, 45, 231, 161; 315/111

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ABSTRACT: A plasma arc thrustor including a hollow core formed from an electrically conductive substance capable of withstanding extremely high temperatures, and radiation flanges engaging the core and formed from a different but lighter material which is capable of conducting heat away from the core. An arc is maintained between an electrode in the hollow portion of the core and a composite electrode consisting of the core and one of the radiation flanges. A coil is located in offset relation to the arc, and radiation shields are interposed between the coil and the radiation flanges.

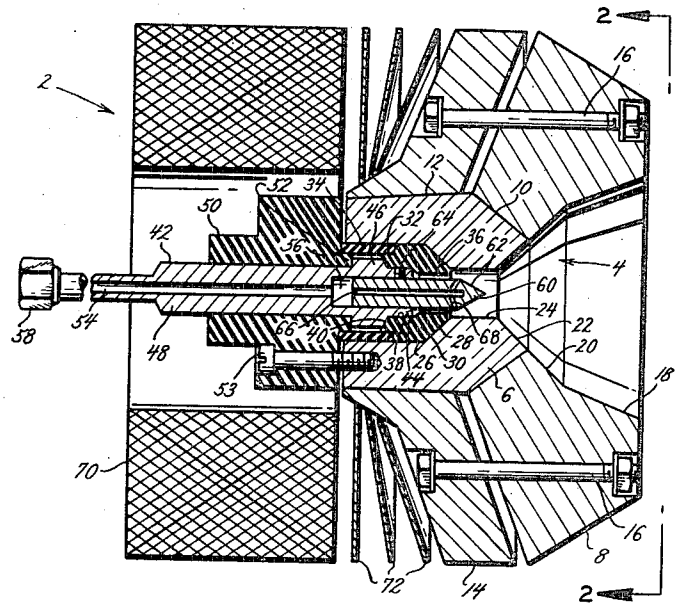
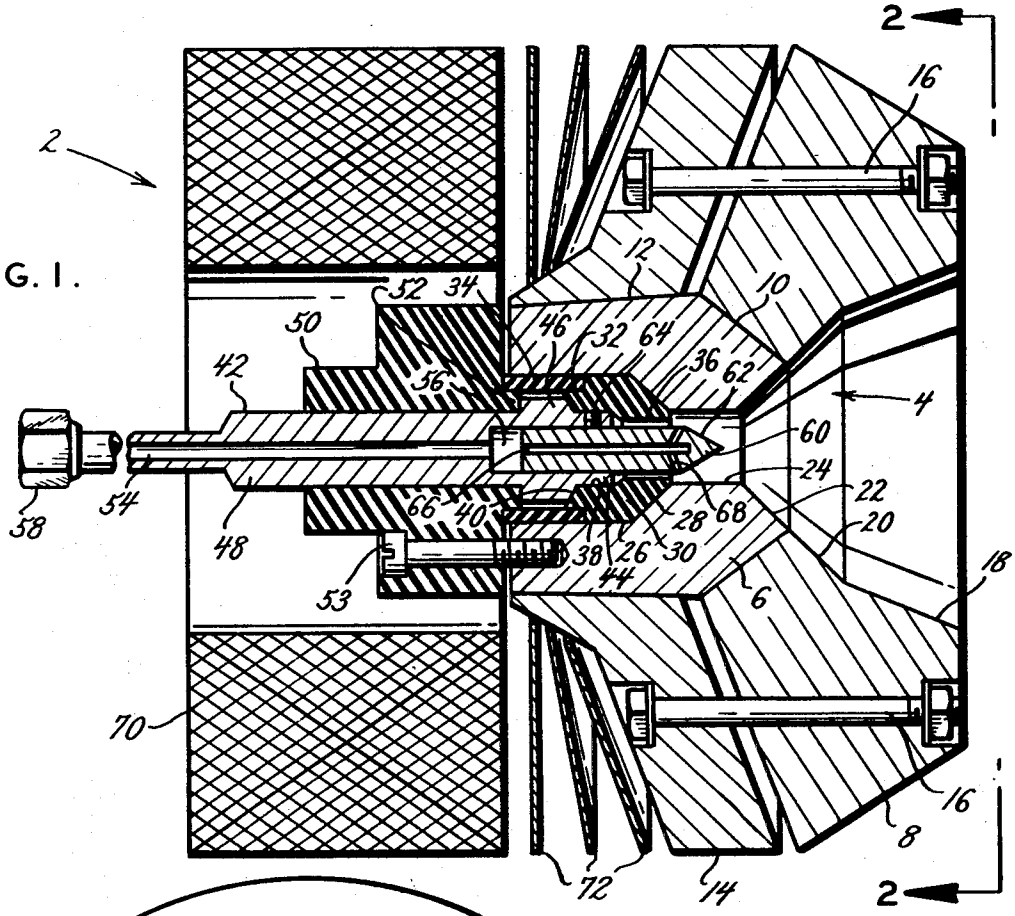


FIG. 1.



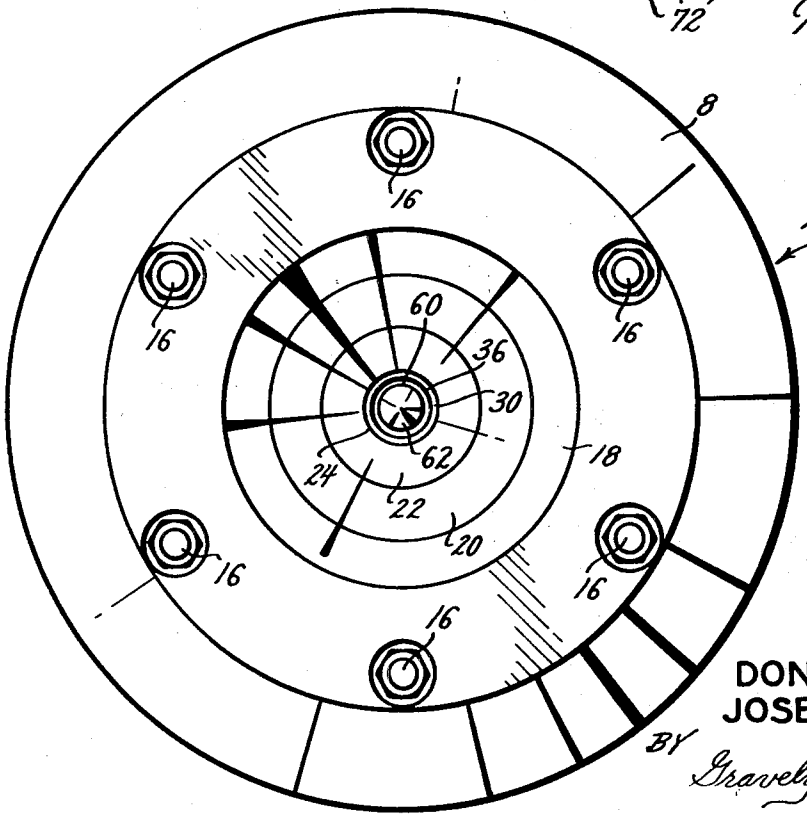


FIG. 2.

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PLASMA ARC THRUSTOR

This invention relates in general to thrustors and more particularly to plasma arc thrustors.

Plasma arc thrustors when operated in low-pressure environments such as beyond the earth's atmosphere develop extremely high velocities with the consumption of relatively little propellent. Whereas conventional rockets which operate on the chemical reaction principle at best develop a specific impulse of about 600, plasma arc thrustors operating without the benefit of a magnetic field produce a specific impulse of approximately 1,000 and when the arc is presented within a magnetic field, the specific impulse can climb to as high as 10,000.

Heretofore plasma arc thrustors have been constructed almost entirely from tungsten, it being the accepted belief that only tungsten, among the available substances for such a purpose, could both withstand the elevated temperatures inherent with such thrustors, and at the same time supply sufficient structural rigidity to the device. Tungsten, however, is one of the heavier elements, having a specific gravity of 19.3, and consequently thrustors fabricated from it have been extremely heavy in comparison to their size. Moreover, the magnets used to increase the thrust of conventional plasma arc thrustors are concentric about the tungsten anode forming part of the thrustor body at about the location of the arc within the body and because of this they receive considerable heat through radiation. As a result, it has been common practice to provide the magnets with coolant channels to dissipate that heat.

One of the principal objects of the present invention is to provide a thrustor suitable for use beyond the earth's atmosphere. A further object is to provide an extremely light plasma arc thrustor. Another object is to provide a plasma arc thrustor which produces a thrust comparable in magnitude to heavier thrustors of the same size. A still further object is to provide a plasma arc thrustor which does not require the circulation of a coolant medium, other than the propellent, through it. An additional object is to provide a thrustor of the type stated which is suitable for use in space vehicles. Still another object is to provide a thrustor which is simple and rugged in construction and economical to manufacture.

These and other objects and advantages will become apparent hereinafter.

The present invention resides in a thrustor having a composite electrode consisting of a core formed from an electrically conductive substance capable of withstanding extremely high temperatures, and radiation means capable of conducting heat away from the core and dissipating that heat through radiation. The thrustor further includes a magnetic field means offset from the arc and radiation shields between the magnetic field means and the radiation means. The invention also consists in the parts and in the arrangements and combinations of parts hereinafter described and claimed. In the accompanying drawings which form part of the specification and wherein like numerals and letters refer to like parts wherever they occur:

FIG. 1 is a sectional view taken along the longitudinal axis of a thrustor constructed in accordance with and embodying the present invention; and

FIG. 2 is a rear elevational view of the thrustor taken along line 2—2 of FIG. 1. Referring now in detail to the drawings, 2 designates a magnetoplasma arc thrustor including a composite anode 4 consisting of an inner core 6 and outer radiation flanges 8 and 14. The core 6 is formed from an electrically conductive substance capable of not only withstanding extremely high temperatures without losing structural rigidity, but also capable of serving as a terminus for an arc without eroding excessively. Tungsten has been found suitable for this purpose. The core 6 is provided with a pair of angularly related tapered surfaces 10 and 12, the former of which is lapped into the base of the outer radiation flange 8 so as to form an intimate interface across which heat will conduct readily away from the core 6. The radiation flange 8 is also

formed from an electrically conductive material which will withstand high temperatures without loosing structural rigidity and, furthermore, will serve as a good conductor for heat. The substance from which the flange 8 is formed is, however, considerably lighter than the substance from which the core 6 is formed. Graphite has been found suitable for this purpose. The other tapered surface 12 on the core 6 is lapped into the base of an inner radiation flange 14, and that flange 14 is formed from a lightweight electrically conductive material which withstands elevated temperatures and is capable of conducting heat readily. Again, graphite has been found to be a substance suitable for this purpose. The radiation flanges 8 and 14 are annular bodies held together and in snug abutment with the tapered surfaces 10 and 12 respectively, on the core 6 by means of a plurality of axially extending circumferentially spaced bolts 16 which urge the flanges 8 and 14 toward one another. The taper of the surfaces 10 and 12 results in the bolts 16 acting to clamp the flanges 8 and 14 on the body of the core 6.

The outer radiation flange 8 is provided with a pair of cavity-forming frustoconical surfaces 18 and 20 which adjoin one another and are concentric about the axial centerline of the core 6. The frustoconical surface 20 forms an uninterrupted continuation of a frustoconical surface 22 of the same pitch in the core 6. At the inner end of the frustoconical surface 22 the core 6 is provided with an axial bore 24 which merges into a counterbore 26 at a tapered shoulder 28. Fitted into the counterbore 26 is an electrical insulator collar 30 formed from a dielectric substance such as boron nitride which is capable of withstanding elevated temperatures. One end of the insulator collar 30 is tapered and lapped into snug abutment with the tapered shoulder 28 so that gases cannot escape across that interface, while at its other end the collar 30 is provided with an annular relief 32 into which an insulator sleeve 34 formed from a similar dielectric substance is fitted. The insulator collar 30 is further provided with an axial bore 36 which opens at one end into the bore 24 of the core 6 and at its opposite end opens into a counterbore 38 which terminates at a tapered end face 40.

The collar 30 supports an electrode carrier 42 formed from a substance such as molybdenum which is capable of withstanding elevated temperatures without loosing structural rigidity. The electrode carrier 42 includes a cylindrical nose 44 which is slidably received in the counterbore 38 of the collar 30. The inner end of the carrier 42 is provided with a tapered annular flange 46 which is lapped into snug engagement with the tapered end face 40 on the collar 30. The flange 46 at its opposite side merges into an elongated shank portion 48 which is embraced by an annular electrical insulator member 50 having a diametrally reduced annular nose portion 52 which, in turn, projects into the insulator sleeve 34 and abuts against the opposite end of the annular flange 46. The insulator member 50 is formed from a high temperature dielectric material such as boron nitride and is drawn up to the core 6 by means of machine screws 53 which pass through the former and thread into the later. Accordingly, the annular nose portion 52 urges the electrode carrier 42 axially inwardly and forces the core 6 and the insulator collar 30 on one hand and the collar 30 and electrode carrier 42 on the other into snug abutment at their lapped interfaces, that is to say, at the tapered shoulder 28 and the tapered end face 40. A fluidtight seal is thereby formed so that gases cannot escape past the collar 30, while the electrode carrier 42 is electrically isolated from the core 6 and the radiation flanges 8 and 14. Internally the electrode carrier 42 is provided with an axially extending duct 54 which opens into a diametrally enlarged bore 56. At its extreme forward end the electrode carrier 42 is provided with a fitting 58 for connecting the duct 54 to a source of pressurized gas (not shown).

The enlarged bore 56 of the electrode carrier 42 receives a cylindrical cathode 60 having an exposed conical end 62 located within the bore 24 of the core 6. The cathode 60 is formed from an electrically conductive substance capable of

withstanding high temperatures such as tungsten and is retained within the enlarged bore **56** of the carrier **42** by a setscrew **64** threaded radially through the nose **44**. The axial disposition of the cathode **60** within the bore **56** can be altered by loosening the setscrew **64**, shifting the cathode **60** axially, and then tightening the setscrew **64** again. Internally the cathode **60** is provided with an axial passageway **66** which communicates with the bore **24** in the core **6** at a point just inwardly from the conical end **62** by means of a plurality of oblique circumferentially spaced ports **68**.

An annular field coil **70** encircles the annular insulator member **50** and the shank portion **48** of the electrode carrier **42** to the rear of the core **6**. Interposed between the opposed annular end faces of the coil **70** and the inner radiation flange **14** are a plurality of axially spaced radiation shields **72** which are formed from a somewhat lighter material than the core **6**, but nevertheless are capable of withstanding elevated temperatures. Molybdenum has been found suitable for this purpose. The radiation shield **72** adjacent to the coil **70** is planar, whereas the ones rearwardly from it are dish shaped.

The plasma arc thrustor **2** operates most efficiently in environments of reduced pressure such as beyond the earth's atmosphere, and in operation a gaseous propellent such as ammonia, hydrogen, lithium, or the like is introduced into the duct **54** under pressure. The propellent flows into the axial passageway **66** of the cathode **60**, and is discharged therefrom into the axial bore **24** of the anode element **4** through the oblique ports **68**. A direct current potential of approximately 40 to 50 volts is impressed across the cathode **60** and the core **6** to establish an arc between the two. This arc heats ans ionizes the propellent and thereby accelerates that propellent to a high velocity. When a current is passed through the field coil **70**, the propellent is accelerated to an even higher velocity in the arc. By reason of this high velocity propellent flow, the arc is extended in the direction of the flow and attaches to the inner surface **24** of the core **6** at the junction of surfaces **24** and **22**. At extremely high velocities and flow rates the downstream terminus of the arc on occasions passes over onto the frustoconical surfaces **20** of the outer radiation flange **8**. Accordingly, both the core **6** and the outer radiation flange **8** function as the anode.

"The field coil **70** accelerates the propellant by reason of the fact that it provides a magnetic field distribution which is almost parallel to the thrust direction in the region of the cathode conical end **62** and diverges downstream from the end **62**. Adopting a cylindrical coordinate system where z is in the thrust direction, the field of the coil **70** has mainly a b_z component at the cathode **60** and in the downstream region has both a B_z and (B_r) component. Acceleration of the propellant arises through the interaction of these magnetic field components with both the applied and induced electrical currents flowing in the ionized propellant. This interaction is commonly referred to as the $(\bar{J}\times\bar{B})$ force and has a component in the trust direction as a result of the interaction of the radial magnetic field (B_r) and an induced azimuthal current (J_θ). A second mechanism in which the field coil **70** plays a role in the acceleration is in the conversion of rotational energy added in the interelectrode region to directed axial kinetic energy downstream through a magnetic nozzle effect. The magnetic field distribution acts much like a physical nozzle in that for the pressures under consideration the charged particles or plasma tend to be following the magnetic field lines. The rotational energy added in the throat is a result of the interaction of the axial magnetic field component (B_z) and the radial electrical current (J_r)."

Some of the heat generated by the arc passes into the core **6** and is conducted through it, across the interfaces at its tapered surfaces **10** and **12**, and into the radiation flanges **8** and **14**. The radiation flanges **8** and **14**, in turn, dissipate the heat primarily by radiation inasmuch as the environment in which the thrustor **2** is designed to operate contains little, if any, gas to effect appreciable dissipation of the heat through convection. The electrode carrier **42** as well as the cathode **60**, on the other hand, are cooled by convection, the heat passing into the relatively cold propellent flowing through the duct **54**, enlarged bore **56** and axial passageway **66** which serve as propellent-injecting means. The radiation shields **72** greatly minimize radiation of heat from the inner radiation flange **14** into the field coil **70**. Moreover, by reason of the fact that the coil **70** is set forward from the cathode **60**, it is not located in the high temperature region directly outwardly from the arc. On the contrary, the coil **70** encircles the annular insulator member **50** which is maintained relatively cool through the effects of heat convection into the flowing propellent. Consequently, the coil **70** operates more efficiently and need not be fabricated from expensive temperature resistant substances; nor need it be provided with coolant passages for circulation of a coolant medium through it.

Since the anode **4** of the thrustor **2** is a composite structure comprising the small and relatively heavy, yet extremely durable, core **6** and the larger relatively light outer radiation flange **8**, the anode **4** is considerably lighter than the anodes of conventional plasma arc thrustors. This, together with the fact that the inner radiation flange **14** is also formed from a light weight substance, reduces the weight of the entire thrustor **2** to about **25** percent of the weight of conventional thrustors capable of providing an equivalent thrust. In other words, the thrustor **2** offers the high specific impulse characteristic of plasma arc thrustors in general, yet is much lighter in weight than thrustors heretofore designed.

This invention is intended to cover all changes and modifications of the example of the invention herein chosen for purposes of the disclosure which do not constitute departures from the spirit and scope of the invention.

What is claimed is:

1. A thrustor comprising a hollow core, radiation means mounted in heat-conducting relation with respect to the core and formed from a material different from the material from which the core is formed, both the radiation means and the core being at the same electrical potential and forming a first electrode, the radiation means and core further defining an outwardly opening cavity into which the hollow portion of the core opens, a second electrode mounted in the hollow portion of the core inwardly from the cavity and having a channel which discharges into the hollow portion of the core for introducing a gaseous propellant into the hollow core, whereby an arc established between the first and second electrodes will pass through the propellant.

2. A thrustor according to claim **1** wherein the core is provided with two oppositely tapered surfaces, where the radiation means comprises a first radiation flange which embraces one of the tapered surfaces, and a second radiation flange which embraces the other of the tapered surfaces, and wherein means are provided for urging the radiation flanges toward one another and axially with respect to the core, whereby the radiation flanges are maintained on the core and snugly abut the tapered surfaces so that heat conducts readily across the interfaces formed thereby.

3. A thrustor comprising a hollow core forming a first electrode, injecting means for introducing a gaseous propellant into the hollow core, a second electrode mounted such that an arc established between the first and second electrodes will pass through the propellant introduced into the hollow core, radiation means formed from a material different from the material from which the core is formed, the core and radiation means being in heat-conducting relation with respect to one another, and magnetic field means axially offset with respect to the portion of the second electrode at which the arc attaches.

4. A thrustor according to claim **3** wherein the magnetic field means is an annular coil substantially concentric with respect to the axial centerline of the core.

5. A thrustor according to claim **4** and further characterized by at least one radiation shield interposed between the coil and radiation means to retard the transference of heat from the radiation means to the coil.

6. A thrustor according to claim 2 wherein an annular coil is mounted concentric with respect to the axial centerline of the core in axially offset relation to the portion of the second electrode at which the arc initiates, and wherein at least one annular heat shield is interposed between the coil and the second radiation flange whereby to retard radiation of heat from the radiation means to the coil.

7. A thrustor comprising a hollow core formed from tungsten and serving as a first electrode, radiation means formed from graphite and mounted in intimate contact with the core so that heat is conducted from the core to the radiation means, a substantial surface area on the graphite radiation means being uncovered and exposed outwardly to open space so that the radiation means radiates heat conducted to it away from the thrustor, the core and radiation means being at the same electrical potential, injecting means for introducing a gaseous propellant into the hollow core, and a second electrode mounted such that an arc established between the first and second electrodes will pass through the propellant introduced into the hollow core.

8. A thrustor according to claim 7 wherein both the core and the radiation means form the first electrode.

9. A thrustor comprising a hollow core, an electrode mounted in the hollow core but being electrically isolated therefrom, the electrode being positioned such that an arc will exist between the core and the electrode when a suitable electric potential is impressed across the core and the electrode, injection means for introducing a gaseous propellant into the hollow core such that the propellent flows through the arc, and radiation means surrounding the hollow core and being formed from a single material which is a different material than the material from which the core is formed, the radiation means being in intimate contact with the outwardly presented surface of the core for substantially the entire length of and entirely around the core so that heat from the arc will be conducted from the core to the radiation means, the radiation means being uncovered and exposed outwardly to open space so that it radiates the heat conducted through it away from the thrustor.

10. A thrustor according to claim 9 wherein the radiation means includes a flange which surrounds the core and has an outwardly opening cavity into which the hollow portion of the core opens.

11. A thrustor according to claim 9 wherein the radiation means and the core, aside from hollow central cavities therein, are substantially solid in cross section and are free of coolant channels so that heat conducts readily through them.