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(54) Abstract Title
Microwave thruster for spacecraft

(57) The thruster comprises a tapered waveguide comprising a section 1, that is evacuated or filled with air, and a section 6 containing a dielectric resonator or ferrite material whose relative permeability or relative permittivity (or both) have values greater than unity. Microwaves may be introduced into the guide via a slot 2, or a probe. It is stated that the force 9, on the end wall 5, due to reflection of the microwaves, is less than the force 4, exerted on the end wall 3, thereby generating a resultant propulsive thrust. The thruster may be used to enable the orbit of a spacecraft to be maintained or changed over a period of time.

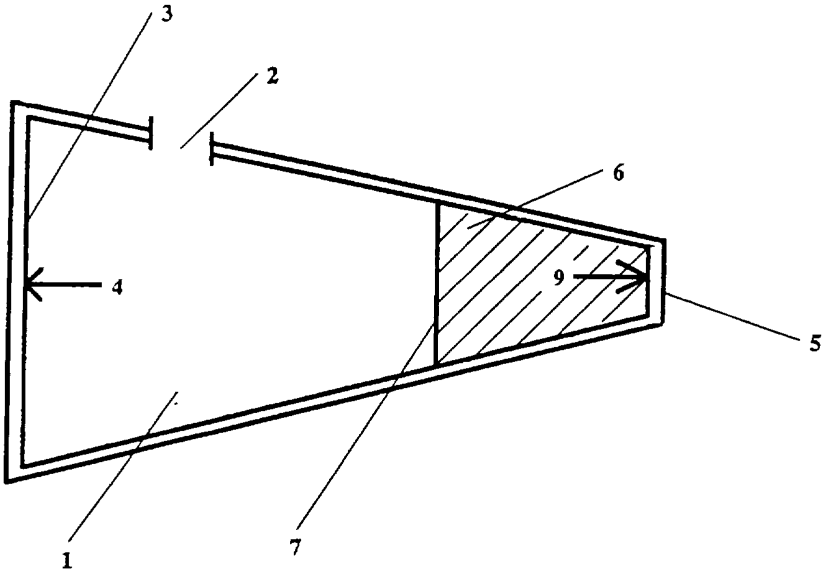

FIGURE 1

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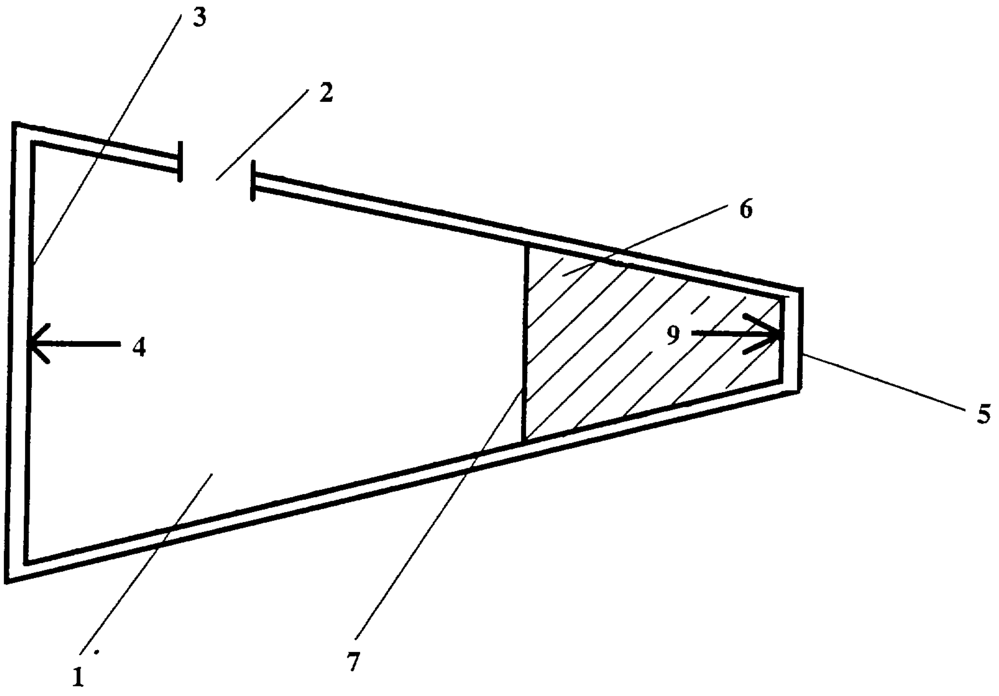

FIGURE 1

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MICROWAVE THRUSTER FOR SPACECRAFT

This invention relates to a microwave thruster for use on spacecraft.

The thruster is used for maintaining or changing the orbits of spacecraft by applying low levels of thrust over long periods of time. It may also be used to change the attitude of the spacecraft.

According to the present invention there is provided a thruster which will generate thrust when supplied with electrical energy at the appropriate frequency, typically in the microwave region. The electrical energy will cause electromagnetic waves to be propagated in the thruster which comprises a shaped resonant waveguide assembly. The assembly includes both an air or vacuum filled section and a section continuing a dielectric resonator or ferrite material. The force resulting from reflections of the guided electromagnetic waves in the section containing a dielectric resonator or ferrite material will be less than the force resulting from reflections in the air or vacuum filled section. The difference between these forces will give rise to a resultant thrust.

A specific embodiment of the invention will now be described by way of example with reference to the accompanying drawing, Figure 1, which shows a schematic diagram of the thruster.

Electrical energy of appropriate frequency is coupled into an air or vacuum filled section of waveguide 1 by means of a slot or probe 2 depending on the required interface with the energy source. For a standard rectangular waveguide interface with the source, a slot is most suitable for coupling to a circular thruster waveguide, enabling a TM01 mode to be propagated through the thruster waveguide. The energy propagates along the waveguide as an electromagnetic wave and is reflected at one end of the air or vacuum filled section by an end wall 3. Reflection of the electromagnetic wave causes a force to be produced on the end wall 3 in the direction of the arrow 4. The electromagnetic wave also propagates towards the other end wall 5. As the wave propagates towards end wall 5, the cross section of the waveguide decreases and the wave enters a Section 6 containing an electrical material.

Thus for waveguide of circular configuration the diameter would decrease from diameter d_1 at end wall 3 to diameter d_2 at end wall 5.

The electrical material will have a relative permeability higher than unity or a relative permittivity higher than unity or both relative permeability and relative permittivity higher than unity. The electrical material will also exhibit low electrical losses. Such an electrical material may be selected from dielectric resonator materials or from ferrite materials. For a thruster operating at 2000 Mhz utilising TM01 mode, a suitable material is a dielectric resonator of relative permittivity value 38.

The dimensions of the waveguide are such that, at the interface 7, between section 1 and section 6, the characteristic impedance of the wave in section 1 is identical to the characteristic impedance of the wave in section 6. This ensures that the wave propagates from section 1 to section 6 and also from section 6 to section 1 without reflection. For a circular waveguide the diameter at the interface would be d_3.

The electromagnetic wave is reflected at the end wall 5 and produces a force on the end wall 5 in the direction of the arrow 9. This force is less than the force at the end wall 3 by a factor dependent on the relative permeability and relative permittivity of the electrical material and by the dimensions of the waveguide at end wall 3 and end wall 5.

The reduction in force at end wall 5 is a result of the decrease in momentum of the electromagnetic wave as the propagation velocity decreases from section 1 to section 6. The decrease in velocity occurs due to two effects.

The first effect is a decrease in propagation velocity due to the increased relative permeability or due to the increased relative permittivity or due to the increase of both relative permeability and relative permittivity of the electrical material in section 6. For a dielectric resonator material of relative permittivity e_r the propagation velocity is decreased by a factor of $\sqrt{e_r}$.

The second effect is a reduction in the group velocity of the electromagnetic wave due to the increase in guide wavelength as the cross section of the waveguide is decreased. Thus for circular waveguide the group velocity in Section 1 decreases as the diameter decreases from d_1 to d_3 and in Section 2 the group velocity decreases as the diameter decreases from d_3 to d_2.

The difference in the forces exerted on the two end walls 3 and 5 will give rise to a resultant force on the thruster unit in the direction of the arrow 4.

This force is given by the equation

$$F = \frac{2P}{C}\left(\frac{\lambda_1}{\lambda_{g1}} - \frac{\lambda_2}{\lambda_{g2}\sqrt{e_r}}\right) \qquad - \qquad (1)$$

where F = Resultant force (Newtons)

P = Input power (watts)

C = Speed of light (m/sec)

λ_1 = free space wavelength (m)

λ_2 = unbounded wavelength in Section 6 (m)

λ_{g1} = guide wavelength at end wall 3 (m)

λ_{g2} = guide wavelengh at end wall 5 (m)

It may be seen from equation (1) that to obtain a force F, the ratio of the free space wavelength to guide wavelength at the end wall 3 must be greater than the ratio of the unbounded wavelength to guide wavelength at the end wall 5 divided by the square root of the relative permittivity of the dielectric.

It may be noted that for circular waveguide, λ_{g1} is dependent on diameter d_1 and λ_{g2} is dependent on on diameter d_2. To maximise the force F these diameters would be chosen within practical constraints to minimise λ_{g1} and to maximise λ_{g2} whilst the value of e_r is maximised consistent with acceptable electrical losses.

The overall length of the two sections of waveguide 1 and 6 will be a multiple of half the effective wavelength of the applied electrical energy, to enable a resonant state to be established. The total resultant force due to the multiple reflections will be increased by a factor dependent on the electrical losses occurring in the waveguide assembly. This factor may be designated the Q factor of the resonant waveguide.

Thus the total thrust generated by the multiple reflections in the unit designated F_T is given by the equation:

$$F_T = \frac{2PQ}{C}\left(\frac{\lambda_1}{\lambda_{g1}} - \frac{\lambda_1}{\lambda_{g2}\sqrt{e_r}}\right) \qquad - \qquad (2)$$

The thrust generated by the unit, due to the total resultant forces, produced as described, can be transmitted to a spacecraft by mechanically fixing the unit together with its source of electrical energy, to the spacecraft structure.

The momentum transferred to the spacecraft by the thruster is equal to the total sum of the momentum changes in the electromagnetic wave at the end walls, thus satisfying the law of conservation of momentum.

The energy lost in the thruster due to electrical losses is less than the energy input to the thruster, by a value equal to the kinetic energy transferred by the thruster to the spacecraft, thus satisfying the law of conservation of energy.

CLAIMS

1. A thruster which will generate thrust when supplied with electrical energy at the appropriate frequency, causing electromagnetic waves to be propagated in the thruster which comprises a resonant waveguide assembly of varying cross sections, and including an air or vacuum filled section and a section containing a dielectric resonator or ferrite material, such that the force resulting from reflections of the guided electromagnetic waves at the end wall of the section containing the dielectric resonator or ferrite material will be less than the force resulting from reflections at the end wall of the air or vacuum filled section, the difference between these forces giving rise to a resultant thrust on the unit.

2. A thruster as claimed in Claim 1. with a means of coupling electrical energy of the appropriate frequency into the waveguide assembly such as a slot in the waveguide wall, or a probe inserted into the waveguide.

3. A thruster as claimed in Claim 1. or Claim 2. which includes a section containing a dielectric resonator or ferrite material whose relative permeability or relative permittivity or both have values greater than unity, and whose electrical losses are low at the frequency of the applied electrical energy.

4. A thruster as claimed in any proceeding claim which includes a waveguide with varying cross section such that at the interface between the air or vacuum filled section and the section containing a dielectric resonator or ferrite material, the characteristic impedance of the electromagnetic wave is the same for both sections, resulting in the propagation of the wave in either direction between the sections without reflection.

5. A thruster as claimed in any proceeding claim which includes a waveguide with varying cross section such that the free space wavelength to guide wavelength ratio at the end wall of the vacuum or air filled sections is high compared to the unbounded wavelength to guide wavelength ratio at the end wall containing a dielectric resonator or ferrite material.

6. A thruster as claimed in any preceding claim whose overall electrical length within the waveguide assembly is a multiple of half the effective wavelength of the applied electrical energy, resulting in a waveguide assembly which is resonant at the frequency of the applied electrical energy.

7. A thruster substantially as described herein with reference to the accompanying drawing Figure 1.

Amendments to the claims have been filed as follows

1. A thruster which will generate thrust when supplied with electrical energy in the form of an electromagnetic wave typically in the microwave region of the electromagnetic frequency spectrum, causing electromagnetic waves to be propagated in the thruster which comprises a resonant waveguide assembly of varying cross sections with two end walls, one at each end of the assembly, and the assembly being divided into an air or vacuum filled section and a section containing a dielectric resonator or ferrite material, such that the force resulting from reflections of the guided electromagnetic waves at the end wall of the section containing the dielectric resonator or ferrite material will be less than the force resulting from reflections at the end wall of the air or vacuum filled section, the difference between these forces giving rise to a resultant thrust on the unit.

2. A thruster as claimed in Claim 1. with a means of coupling electrical energy, in the form of an electromagnetic wave typically in the microwave region of the electromagnetic frequency spectrum, into the waveguide assembly, such means being typically a slot in the waveguide wall, or a probe inserted into the waveguide.

3. A thruster as claimed in Claim 1. or Claim 2. in which the said section containing a dielectric resonator or ferrite material, whose relative permeability or relative permittivity or both have values greater than unity, and whose electrical losses do not prevent use of the thruster at the frequency of the applied electrical energy.

4. A thruster as claimed in any proceeding claim which includes said waveguide with varying cross section such that at the interface between the air or vacuum filled section and the section containing a dielectric resonator or ferrite material, the characteristic impedance presented to the electromagnetic wave by the said waveguide is the same for both sections, resulting in the propagation of the wave in either direction between the sections without reflection.

5. A thruster as claimed in any proceeding claim which includes a waveguide with varying cross section such that the free space wavelength to guide wavelength ratio at the end wall of the vacuum or air filled sections is higher than the unbounded wavelength to guide wavelength ratio at the end wall containing a dielectric resonator or ferrite material.

6. A thruster as claimed in any preceding claim, whose overall electrical length between the two said end walls is a multiple of half the effective wavelength of the applied electrical energy, resulting in a waveguide assembly which is resonant at the frequency of the applied electrical energy.

7. A thruster substantially as described herein with reference to the accompanying drawing Figure 1.

Patent Office

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Claims searched: 1-7
Examiner: C B VOSPER
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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:
UK Cl (Ed.Q): F1J(JXX); H1W (WX)
Int Cl (Ed.6): F03H 3/00,5/00
Other: ONLINE; EPODOC, PAJ, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2229865 A	SHAWYER (see whole document)	1-6
A	GB 1521327	MESSERSCHMITT (page 1, lines 43-48)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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