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(56) Documents Cited:
GB 2334761 A **GB 2229865 A**
CN 001072244 A **JP 580032976 A**
US 5052638 A **US 4754601 A**

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(54) Abstract Title: **Thrust producing device using microwaves**

(57) A microwave engine, which produces high thrust, may be used to propel spacecraft where the thrust vector is at ninety degrees to the main velocity vector. It may also be used in an airborne vehicle to counteract gravitational force. The engine comprises a gimbal mounted matrix of a number of superconducting microwave thrusters 11 which are supplied with pulses of microwave energy via an array of switches 15 and enclosed in a Dewar 19 which is maintained at low temperature by liquefied gas. The engine may include an automatic control system to maintain the correct frequency of the microwave generator 7, a means 17 of dissipating the stored microwave energy, and a gyroscopic instrument 21 and motors 22,23 for maintaining the axis of thrust parallel to the direction of gravitational acceleration for an airborne vehicle.

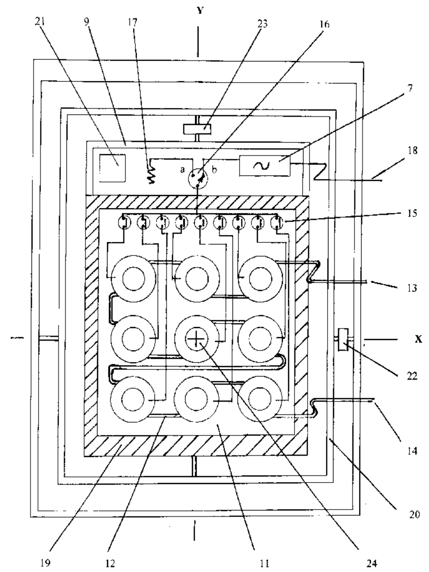

Figure 2

The claims were filed later than the filing date but within the period prescribed by Rule 25(1) of the Patents Rules 1995.

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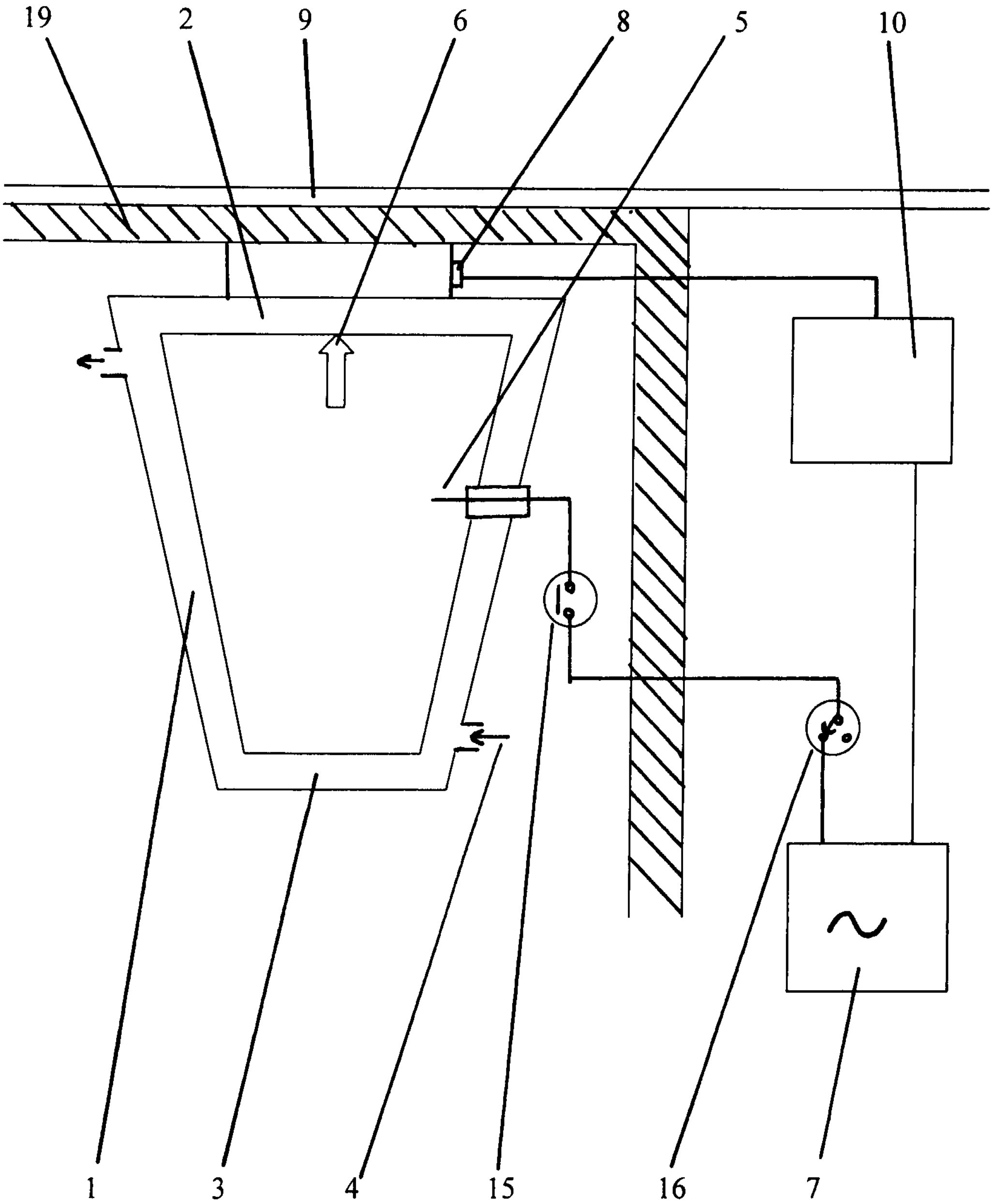

Figure 1

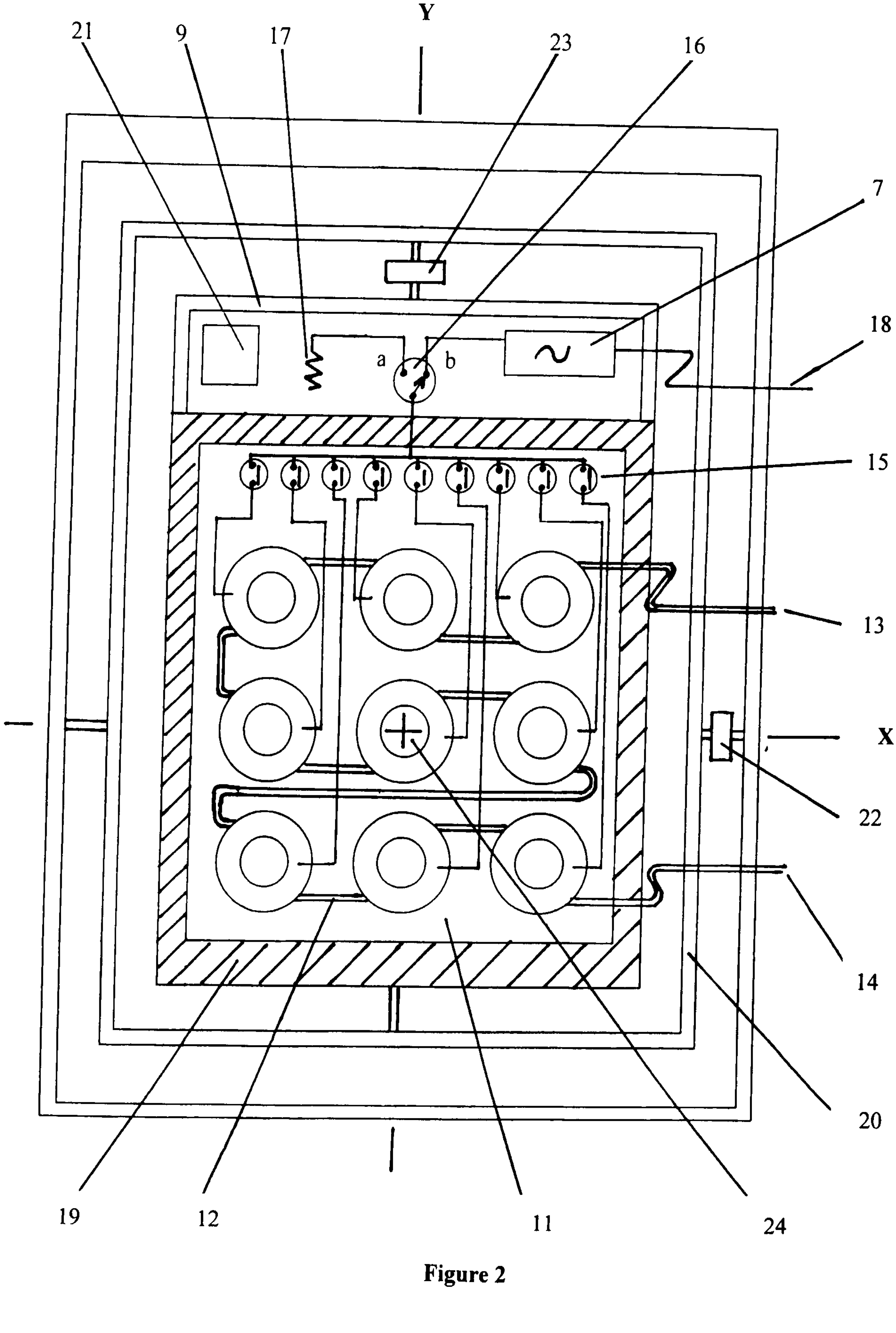

Figure 2

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HIGH THRUST MICROWAVE ENGINE

This invention relates to a microwave engine, which produces high thrust and may be used in spacecraft missions where the thrust vector is at ninety degrees to the main velocity vector. It may also be used in an airborne vehicle to counteract gravitational force, thus enabling the vehicle to be moved horizontally or vertically with low levels of auxiliary thrust.

Previously described microwave thrusters used for spacecraft propulsion do not produce the necessary thrust for these applications, as they are designed to provide kinetic energy along the main velocity vector.

The object of this invention therefore is to provide a microwave thruster operating at a very high Q value, such that an engine comprising a number of these thrusters will produce the necessary total thrust.

According to the present invention, there is provided an engine comprising a gimbal mounted matrix of a number of superconducting microwave thrusters, which are supplied with pulses of microwave energy via an array of switches, and enclosed in a dewar, which is maintained at low temperature by liquefied gas.

A specific embodiment of the invention will now be described by way of example, with reference to the accompanying drawings in which:-

Figure 1 shows a schematic diagram of a single thruster.
Figure 2 shows a schematic diagram of the complete engine.

In Figure 1, the inner surface of the tapered waveguide section 1, and the end walls 2 and 3, are coated with a material which exhibits superconducting properties at low temperature. Liquefied gas 4 flows through the hollow walls of the tapered waveguide section 1 and the hollow end walls 2 and 3 to produce a temperature that is low enough to maintain the superconducting properties of the inner coating. A pulse of electrical energy in the form of an electromagnetic wave in the microwave region of the electromagnetic frequency spectrum is coupled into the tapered waveguide section by means of a slot or probe 5 in the side wall of the waveguide. A force is therefore produced in the direction shown by the arrow 6. This force is given by the general equation:

$$F = \frac{2PQD}{c}, \qquad (1)$$

where F = force (Newtons),

P = input power (Watts),

c = speed of light (metres per second),

D = design factor, dependent on the geometry of the thruster.

The factor Q in equation (1) is the number of multiple reflections at power P which occur when the frequency of the input power equals the resonant frequency of the thruster.

The frequency of the input power may be altered at the microwave generator 7 to closely track any changes in the resonant frequency of the thruster. This is achieved by means of an automatic control system comprising a force sensor 8, mounted on the attachment between the thruster and the engine frame 9, together with a control unit 10. The control unit 10 compares the force measurements from the force sensor 8 for small positive and negative increments in frequency and calculates the optimum frequency for maximum force. This frequency is then maintained until any reduction in force is detected, whereupon the frequency optimisation process is repeated.

The factor Q is given by the equation:

$$Q = \frac{P_c}{P_e}, \qquad (2)$$

where P_c = circulating power (Watts),

P_e = electrical power loss (Watts).

In a superconducting waveguide P_e approaches zero and Q reaches very high values, leading to high levels of force from the thruster. If this force is not used to move the thruster, then no kinetic energy is extracted from the thruster and the Q remains at the very high value, designated Q_u, the unloaded Q. If the force is used to accelerate the thruster, then the Q is reduced to a value designated Q_l, the loaded Q. The value of Q_l may be determined by solving the following equation:

$$\left(\frac{Q_l}{Q_u}\right)^2 + \frac{2Q_l D\bar{v}}{c} = 1, \qquad (3)$$

where $\bar{v}$ is the average velocity reached by the thruster during a period of acceleration, caused by the force F. If the thruster velocity is caused by any means other than the force from that thruster, $\bar{v}$ remains zero and Q_l remains at the same value as Q_u.

Therefore if a spacecraft to which the thruster is attached is travelling at high velocity, operating the thruster with the thrust vector at ninety degrees to the velocity vector will enable an increase in resultant velocity to be achieved with only a small decrease of Q_u, therefore maintaining the required level of force according to equation 1. There are spacecraft missions where such an application of this ninety degree thrust vector is particularly appropriate, including spiral planetary orbits and asteroid deflection. For other missions, operating the thruster with the thrust vector at plus ninety degrees and minus ninety degrees to the velocity vector for alternating periods would enable a resultant velocity increase to be achieved without an unacceptable decrease of Q_u. Such an unacceptable decrease in Q_u would be where the reduction in the resulting force, according to equation 1, was no longer sufficient to give the required acceleration along the thrust vector.

In an airborne vehicle the thruster may be used to counteract gravitational force by aligning the thrust vector with the direction of gravitational acceleration. Provided that the thruster does not significantly contribute to acceleration along the thrust axis, auxilary thrust producing devices will enable the vehicle to be moved horizontally or vertically without an unacceptable decrease of Q_u. Such an unacceptable decrease in Q_u would be where the resulting force, according to equation 1, was no longer sufficient to counteract the gravitational force on the vehicle.

In Figure 2 a number of thrusters are mounted, in layers, on a common structure to form a matrix 11. In Fig 2 only one layer of nine thrusters is shown for clarity. The total thrust from the engine is given by the sum of the forces from each thruster. The thrusters are interconnected by pipes 12, to allow the free flow of liquefied gas which is supplied via flexible pipes 13 and 14. Each thruster is supplied with microwave energy via feeds from a switch array 15. The input to the switch array 15 is fed from a selector switch 16. One connection to the selector switch 16, namely terminal a, is fed to a resistive load 17, which provides a means to dissipate the total microwave energy, stored in the thruster matrix 11, as heat. The other connection to the selector switch 16, namely terminal b, is the feed from the microwave generator 7, which is itself supplied with d.c. electrical energy via a flexible connection 18. With the selector switch 16 positioned to terminal b, a pulse of microwave energy, at the resonant frequency of the thruster, is fed to each thruster in turn. The thruster is selected by closing the appropriate switch in the switch array 15 for the time required to transmit the pulse. The pulse period is determined by the design of the thruster and Q_u. The amplitude of the power of the pulse is determined by the total thrust required from the engine. To reduce the engine thrust, the selector switch 16 is positioned to terminal a, and the appropriate switches in the array 15 are closed for a time required to transmit stored energy in the thrusters to the load 17. The thruster matrix 11 and switch array 15 are enclosed in a dewar 19, which is highly insulated to minimise heat flow. The dewar 19, selector switch 16, load 17 and microwave generator 7 are attached to the engine frame 9.

The engine frame 9 is mounted to the body of the spacecraft or airborne vehicle by a gimbal mechanism 20. In a spacecraft, this mechanism enables the thrust vector to be altered independently of the velocity vector. In an airborne vehicle, the attitude of the engine frame 9 may be measured, in both X and Y axes, by a gyroscopic instrument 21, with reference to the direction of gravitational acceleration, i.e. the local vertical. Signals from the gyroscopic instrument 21, which is attached to the engine frame 9, are used to drive the gimbal mechanism 20 in the X axis, by a control motor 22, and in the Y axis by a control motor 23. In this manner the axis of thrust of the engine is maintained parallel to the direction of gravitational acceleration. The centre of gravity of the engine and that of the vehicle to which it is attached, is along the centre line 24 of the Z axis of the thruster matrix 11. Multiple engines may be employed in vehicles with variable centres of gravity. Horizontal or vertical movement of the vehicle is provided by auxiliary thrusters.

CLAIMS

1. An engine comprising a gimbal mounted matrix of a number of superconducting microwave thrusters which are supplied with pulses of microwave energy via an array of switches and enclosed in a dewar which is maintained at low temperature by liquefied gas.

2. An engine as claimed in Claim 1 with the means of altering the frequency of the microwave generator such that it always equals the resonant frequency of the thruster to which it is connected, such means being an automatic control system comprising a thrust sensor and a control unit.

3. An engine as claimed in Claim 1 or Claim 2 which may be operated with the thrust vector at ninety degrees to the velocity vector of a spacecraft to which it is attached.

4. An engine as claimed in any preceding claim with a selector switch enabling the stored microwave energy in the thruster matrix to be transmitted to a resistive load external to the dewar and to be dissipated as heat.

5. An engine as claimed in any preceding claim with the means of maintaining the axis of thrust of the engine parallel to the direction of gravitational acceleration for an airborne vehicle, such means being a gyroscopic instrument and control motors on the x and y axis of the gimbal mechanism.

6. An engine substantially as described herein with reference to the accompanying drawings Figure 1 and Figure 2.

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Application No:	GB0305709.8	**Examiner:**	Chris Vosper
Claims searched:	1-6	**Date of search:**	15 July 2004

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular reference
A	-	GB 2334761 A SHAWYER
A	-	GB 2229865 A SHAWYER
A	-	US 5052638 A MINOVITCH
A	-	US 4754601 A MINOVITCH
A	-	JP 58032976 A KUSUE
A	-	CN 1072244 A YANG

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[W] :

F1J; H1W

Worldwide search of patent documents classified in the following areas of the IPC[07]

F03H; H01P

The following online and other databases have been used in the preparation of this search report

ONLINE:EPODOC,JAPIO,WPI,OPTICS