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GB 2399601 A **GB 2334761 A**
GB 2229865 A **WO 2007/089284 A2**

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(54) Title of the Invention: **High Q microwave radiation thruster**
Abstract Title: **A high Q microwave radiation thruster**

(57) A high Q microwave radiation thruster, used to accelerate a spacecraft or an airborne vehicle, comprises a tapered resonant cavity 10, with end plates 5 and 9. The endplates have internal convex and concave shapes to create a geometry such that every point on the wavefront of the propagated electromagnetic wave, within the cavity, has the same path length between the end plates. The thruster includes expanding elements 6, which control the axial length of the cavity, such that the Doppler shift, caused by an acceleration of the cavity, can be compensated by a change of axial length. The thruster also includes means of controlling the pulse length and offset frequency of the input microwave power, in response to the acceleration of the cavity.

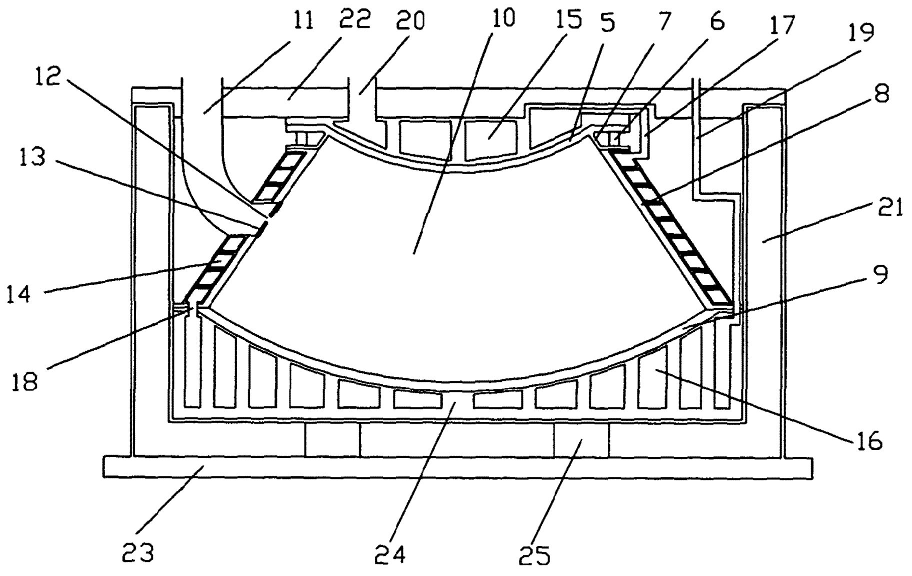

Fig 2 High Q Thruster

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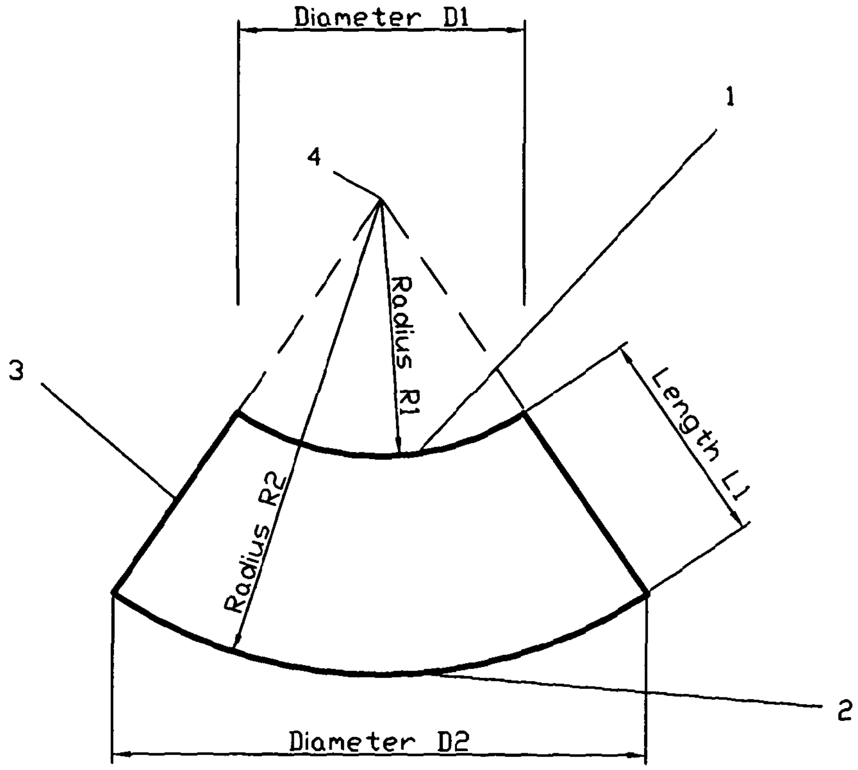

Figure 1 Cavity Geometry

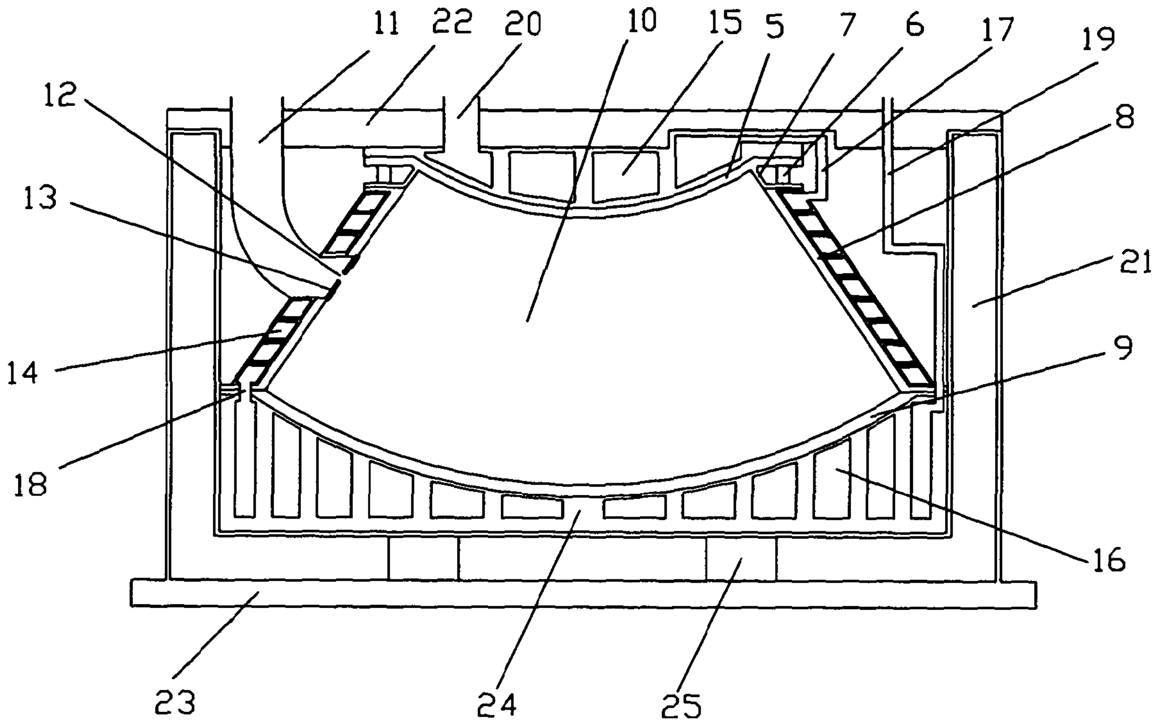

Fig 2 High Q Thruster

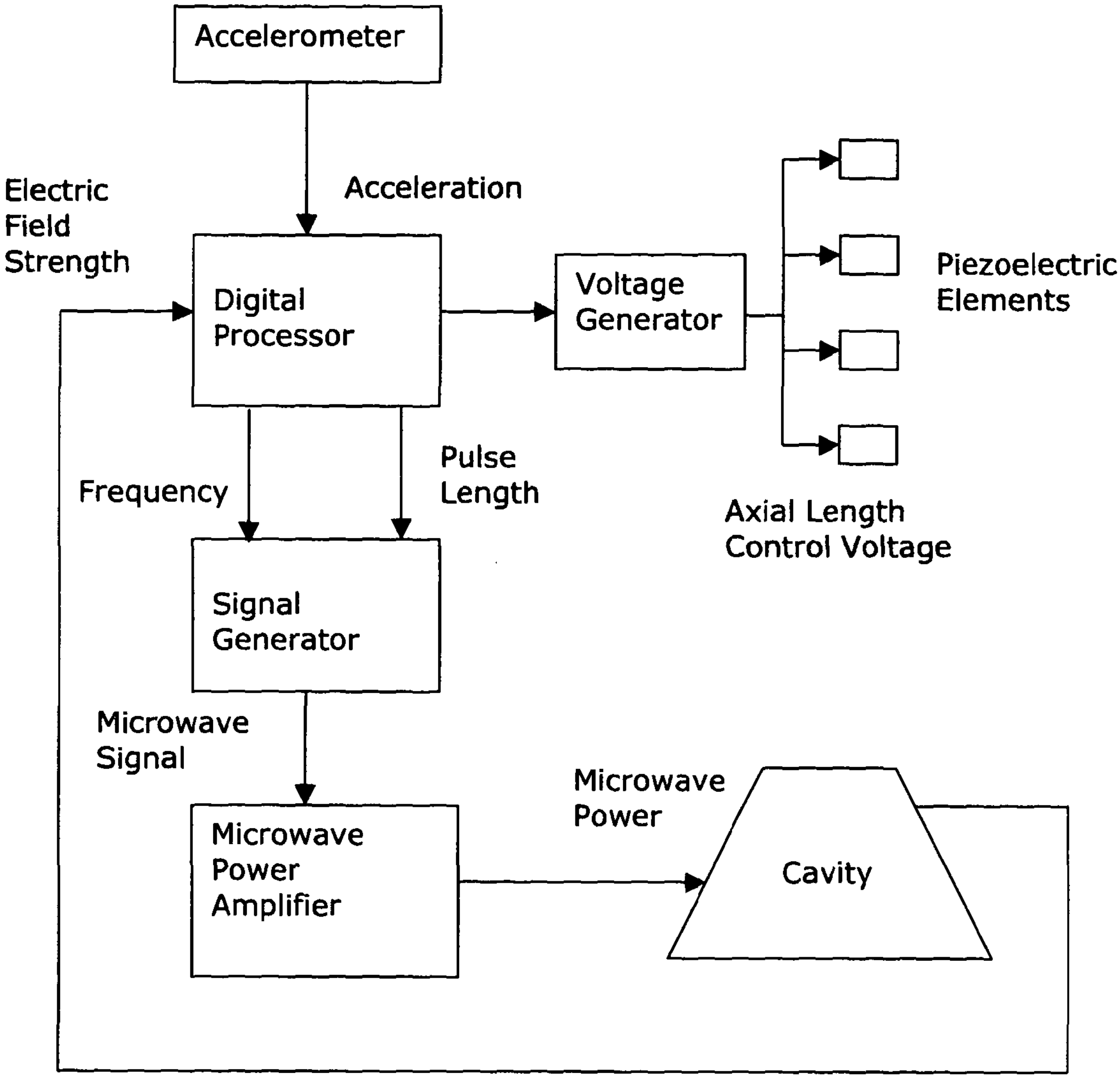

Figure 3. Block Diagram of Control Circuit

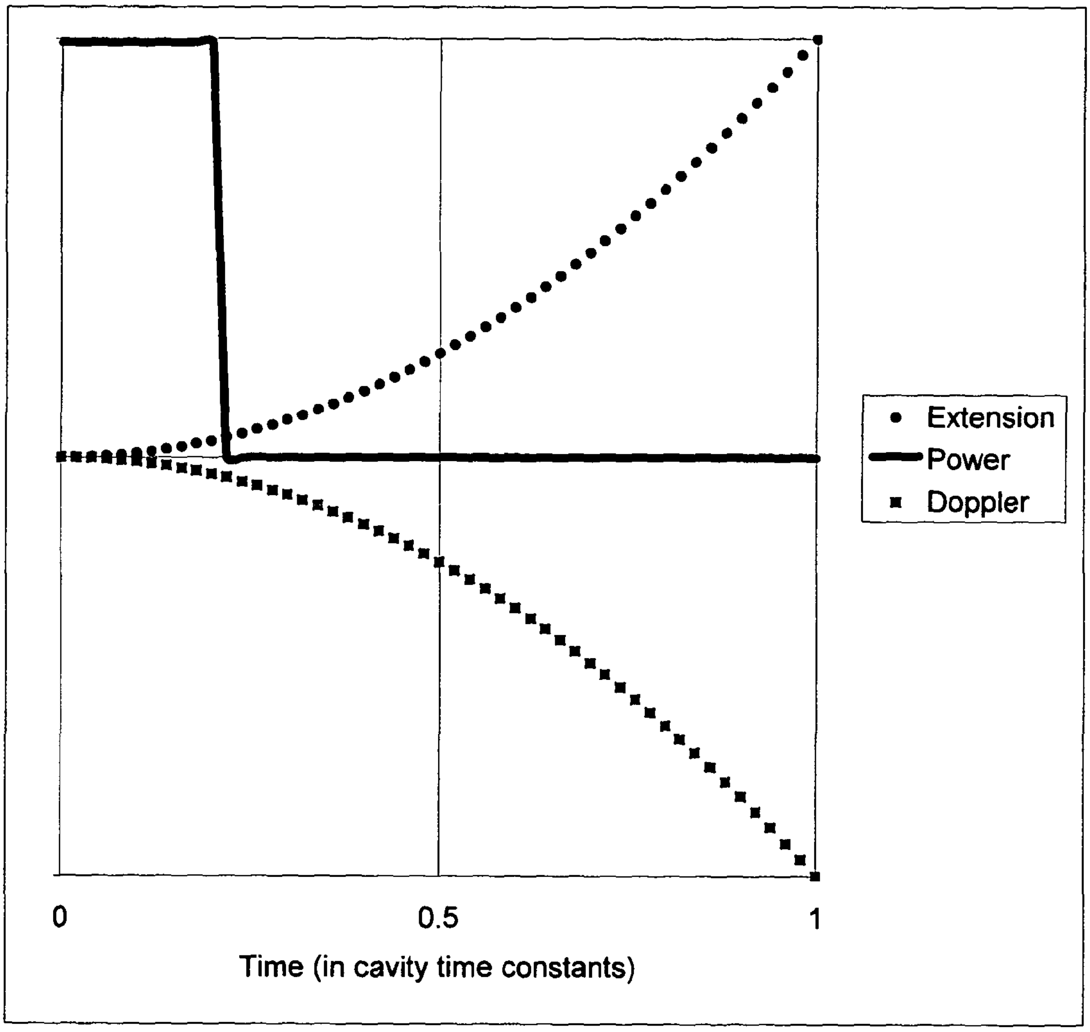

Figure 4. Axial length extension, microwave input power and Doppler frequency shift, for positive cavity acceleration over a single cavity time constant

HIGH Q MICROWAVE RADIATION THRUSTER

This invention relates to a microwave radiation thruster, used to accelerate a spacecraft or an airborne vehicle, as has been previously described, and sometimes referred to as an "EmDrive" thruster.

The thruster comprises a tapered resonant cavity where the force resulting from reflections at the small end plate is less than the force resulting from reflections at the large end plate, due to the decrease in guide velocity of the propagated electromagnetic wave as it approaches the small end plate. The difference in reflection forces is multiplied by the Q factor of the cavity, allowing useful levels of thrust to be achieved with high Q cavities. A method of providing very high Q values is to utilise superconducting material to form the inner surfaces of the cavity, and to cool the cavity to the low temperature required in order to achieve a superconducting condition, by use of a liquefied gas.

The object of this invention is first to increase the Q factor of the thruster cavity by means of the geometry of the cavity, and hence increase the specific thrust, which may be measured in N/kW. A further objective is then to enable this increased specific thrust to be used to accelerate the vehicle to which the thruster is attached, whilst minimising the decrease of loaded Q caused by the acceleration. This decrease in loaded Q is caused by a Doppler shift in the frequency of the propagated electromagnetic wave within the cavity, with the resulting frequency no longer corresponding to the natural resonant frequency of the cavity.

According to the present invention there is provided a tapered microwave cavity with internal concave and convex shaped end plates to reduce the variation in path length across a wavefront of the propagated electromagnetic wave. These shaped end plates enable a high Q to be achieved by minimising the phase distortion across the wavefront.

In addition, the smaller end plate is mounted on piezoelectric elements; thus enabling the axial length of the cavity to be lengthened as the cavity acceleration causes the frequency of the propagated wave to decrease, due to the Doppler effect. This decrease in frequency would otherwise result in a decrease in loaded Q factor, as the frequency of the propagated wave moves below the resonant frequency of the cavity. Increasing the axial length compensates for the decrease in propagated frequency, thus maintaining resonance within the cavity. The level of acceleration sensed by an accelerometer is used as a means of controlling the voltage applied to the piezoelectric elements, and thus the change of axial length of the cavity.

A further feature of the present invention is the variation of the microwave, input frequency, together with the pulse length of the input microwave signal. These functions are varied according to the level of acceleration experienced by the cavity, which is sensed by the accelerometer. The variation of these parameters ensures that the frequency shift that occurs within the input pulse does not take the resulting frequency outside the predetermined bandwidth of the resonant cavity.

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 the geometry of the microwave cavity

Figure 2 shows a schematic diagram of the high Q thruster

Figure 3 shows a block diagram of the circuit used to control the frequency and the pulse length of the input microwave signal, and the piezoelectric voltage.

Figure 4 shows a data plot of typical axial length extension, microwave input power, and Doppler frequency shift, for positive cavity acceleration over a single cavity time constant.

In Figure 1, the cavity comprises a small end plate 1, of diameter D1, a large end plate 2 of diameter D2 and a truncated conical section of wall 3, of length L1. The cone angle is set by the position of the intersection of the wall extension lines at point 4. From this point 4, the radius line R1 defines the cavity internal convex shape of plate 1 and the radius line R2 defines the cavity internal concave shape of plate 2. The electromagnetic wave propagates from plate 1 to plate 2 with every point on the wavefront travelling along a radius line centred at point 4. Thus the path length of any point on the wavefront is identical, and equal to length L1. This constant path length over the wavefront ensures that phase distortion over the large number of reflections within the high Q cavity is minimised, and the value of Q that is achieved in practice approaches the theoretical maximum.

Diameter D1 is chosen such that the propagation of the electromagnetic wave approaches cut-off conditions in the chosen mode. Thus the guide velocity approaches zero and the guide wavelength approaches infinity. Diameter D2 is chosen such that the propagation of the electromagnetic wave approaches free space conditions, where the guide velocity approaches the speed of light, and the guide wavelength approaches the free space wavelength.

In Figure 2, the small end plate assembly 5 includes a number of piezoelectric elements 6, which control the length of the thin wall section 7. The small end plate assembly 5 is fixed to the conical wall section 8 which is fixed to the large end plate 9, to form the complete resonant cavity 10.

Microwave power is fed to the cavity along the input waveguide 11, with the input impedance matched by the slot 12 in the iris plate 13. Other input configurations may be employed including co-axial lines, with loops or probes used to launch the electromagnetic wave into the cavity.

The cavity wall 8 and end plates 5 and 9 are either manufactured from a superconducting material such as the metal niobium, or are coated with a high temperature superconducting film such as YBCO. A liquefied gas at low temperature, such as liquid helium or liquid hydrogen, is circulated through the coolant channels 14, 15 and 16 in the cooling shrouds. These three shrouds each enclose one of the elements of the cavity, namely the cavity wall 8, the small end plate 5 or the large end plate 9. The coolant channels in the three shrouds are interconnected by means of the pipes 17 and 18. The liquefied gas enters via pipe 19 and exits, in gaseous form, via pipe 20. The evaporation of the liquefied gas, as it circulates through the three shrouds, removes the heat generated at the internal surfaces of the cavity. This heat results from the microwave energy dissipating due to circulating currents in the superconducting material. The removal of this heat ensures that the temperature of the material is low enough to maintain the required low value of surface resistance, which occurs when the material is in its superconducting state. This low value of the surface resistance ensures a high value of Q.

To minimise the transfer of heat from the external environment to the coolant, the shrouded cavity is enclosed by a vacuum dewar 21, with an insulated top plate 22. The thrust generated within the cavity is transferred to the base of the dewar 23, via the thick sections of the large end plate shroud 24, and a thrust ring 25.

The dewar may be fixed directly to the vehicle, or by means of a gimbal mechanism to ensure that the thrust vector is always aligned in the opposite direction to the gravitational force vector.

In figure 3, a block diagram shows the circuit used to control the piezoelectric voltage and the frequency and pulse length of the input microwave signal. An accelerometer is mounted on the vehicle being accelerated by the thruster. A signal representing the acceleration is sent to a digital processor, which uses a predetermined algorithm to calculate the axial length control voltage. A signal is sent from the digital processor to the voltage generator, which then provides the correct axial length control voltage to the piezoelectric elements 6, as previously shown in figure 2.

Further predetermined algorithms in the digital processor are used to calculate the necessary frequency offset and pulse length for the microwave signal. This information is sent to the signal generator, which sends a low level microwave signal to a microwave power amplifier. The output power from the microwave amplifier is then sent to the cavity, via the input waveguide 11, as previously shown in figure 2.

The electric field strength within the cavity is monitored, and a signal representing the level of the electrical field is sent to the digital processor. The processor then adjusts the frequency of the microwave signal, using a predetermined algorithm, to maximise the electric field strength within the cavity. This feedback circuit ensures that the frequency offset, calculated from the acceleration input, is added to the natural resonant frequency of the cavity, corrected for any temperature changes in the cavity itself.

In figure 4, typical data is plotted for the axial length extension, microwave input power and Doppler frequency shift, for positive cavity acceleration over a single cavity time constant. The cavity time constant is defined as the time taken for the electric field strength in the cavity to decay to a designated fraction of the maximum field strength, following the end of the input power pulse.

Under positive acceleration conditions, the velocity of the vehicle, and hence the cavity, increases throughout the period of one time constant. This causes the frequency of the propagated microwave pulse to be decreased by the Doppler shift appropriate the change in plate velocities, relative to the guide velocities, as each internal reflection takes place at the end plates. The Doppler frequency shift is shown in figure 4.

To compensate for the decrease in frequency of the propagated electromagnetic wave, the cavity axial length is increased as shown in figure 4. This maintains the cavity in resonance throughout the period of one time constant. The axial length extension is achieved by the piezoelectric elements 6, as previously shown in figure 2, controlled by the circuit as shown in figure 3.

Note that the thruster may be used to slow down the vehicle by directing the thrust vector in a direction opposite to the direction of travel. Under these negative acceleration conditions, the Doppler shift would be positive. The piezoelectric elements would be allowed to contract from a pre-expanded state at zero acceleration, to reduce the axial length of the cavity and thus maintain resonance.

The microwave, input power is shown as a pulse in figure 4. The length of this pulse is determined by the digital processor shown in figure 3, such that the Doppler shift over the period of the pulse does not shift the frequency of the pulse outside the bandwidth of the cavity. The bandwidth of the cavity is determined by the value of the natural Q of the cavity. In order to optimise the pulse length, an offset in the input microwave signal frequency is calculated in the digital processor. This frequency offset is calculated, so that the Doppler shifted frequency passes through the natural resonance frequency of the cavity at a predetermined time during the pulse period.

CLAIMS

1. A high Q microwave radiation thruster, capable of accelerating a spacecraft or airborne vehicle, which has a tapered microwave cavity with internal convex and concave shaped end plates, such that the radii of curvature of these end plates ensure every point on the wavefront of the propagated electromagnetic wave has the same path length between the end plates.

2. A microwave radiation thruster, as claimed in claim 1, employing expanding elements which are used to control the axial length of the cavity, in response to the acceleration of the cavity

3. A microwave radiation thruster, as claimed in claim 1 or claim 2, with the means of controlling the pulse length of the input microwave power, in response to the acceleration of the cavity.

4. A microwave radiation thruster, as claimed in any preceding claim, with the means of offsetting the input microwave frequency by a value which ensures, that under cavity acceleration conditions, the Doppler shift in the propagated microwave frequency, passes through the natural resonant frequency of the cavity at a predetermined point in the input pulse period.

5. A microwave radiation thruster substantially as described herein, with reference to the accompanying drawings, figure 1, figure 2, figure 3 and figure 4.

Application No:	GB1113261.0	**Examiner:**	Mr Hal Young
Claims searched:	1-5	**Date of search:**	16 November 2011

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 relevance
A		GB2334761 A (SHAWYER)
A		GB2399601 A (SHAWYER)
A		GB2229865 A (SHAWYER)
A		WO2007/089284 A2 (FETTA)

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^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F03H; H02N; H05B

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

WPI, EPODOC, TXTUS0, TXTUS1, TXTUS2, TXTUS3, TXTUS4, TXTEP1, TXTGB1, TXTWO1

International Classification:

Subclass	Subgroup	Valid From
F03H	0099/00	01/01/2009
F03H	0003/00	01/01/2006
H02N	0011/00	01/01/2006