How the Thrust of Shawyer's Thruster can be Strongly Increased

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Here, we review the derivation of the equation of thrust of Shawyer's thruster, by obtaining a new expression, which includes the indexes of refraction of the two parallel plates in the tapered waveguide. This new expression shows that, by strongly increasing the index of refraction of the plate with the largest area, the value of the thrust can be strongly increased.

Key words: Satellite Propulsion, Quantum Thrusters, Shawyer's Thruster, Radiation Pressure, Microwave Energy.

1. Introduction

Recently a NASA research team has successfully reproduced an experiment [1] originally carried out by the scientist Roger Shawyer [2], which point to a new form of electromagnetic propulsion, using microwave. The Shawyer device is a thruster that works with radiation pressure. It provides directly conversion from microwave energy to thrust. In the Shawyer thruster the microwave radiation is fed from a magnetron, via a tuned feed to a closed *tapered waveguide*, whose overall electrical length gives resonance at the operating frequency of the magnetron. The incidence of the microwave radiation upon the opposite plates R1 and R2, in the tapered waveguide, produce force F_{g1} and F_{g2}, respectively (See Fig.1). The area of R1 is much greater than the area of R2, therefore the power incident on R1 is much greater than the power incident on R2. Consequently, the force F_{g1} exerted by the microwave radiation upon the plate R1 is much greater than the force F_{g2} exerted upon the plate R2. In the derivation of the expressions of F_{g1} and F_{g2}, Shawyer assumes *total reflection* of the radiation incident upon both plates. Thus, the expression of the thrust T obtained by him is

$$T = F_{g1} - F_{g2} = \frac{2P_0}{c}\left(\frac{v_{g1}}{c} - \frac{v_{g2}}{c}\right) \qquad (1)$$

where v_{g1} and v_{g2} are the group velocities of the incident radiation on the plates R1 and R2, respectively; P_0 is the radiation power and c is the speed of light in free-space.

Here, we review the derivation of Eq. (1), obtaining a new expression for T, which includes the indexes of refraction n_{r1} and n_{r2} of the plates R1 and R2, respectively. This new expression shows that, by increasing the index of refraction of R1, the value of T can be strongly increased.

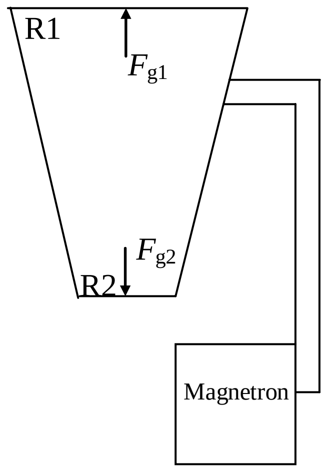


Fig. 1 – Schematic diagram of Shawyer's thruster.

2. Theory

Consider a beam of photons incident upon a flat plate, perpendicular to the beam. The beam exerts a *pressure*, dp, upon an area $dA = dxdy$ of a volume $dV = dxdydz$ of the plate, which is equal to the energy dU *absorbed* by the plate per unit volume (dU/dV).i.e.,

$$dp = \frac{dU}{dV} = \frac{dU}{dxdydz} = \frac{dU}{dAdz} \quad (2)$$

Substitution of $dz = vdt$ (v is the speed of radiation through the plate; $v = c/n_r$, where n_r is the *index of refraction* of the plate) into the equation above gives

$$dpdA = \frac{(dU/dt)}{v} \quad (3)$$

Since $dpdA = dF$ we can write:

$$dF = \frac{dU/dt}{v} = \frac{dP}{v} \quad (4)$$

By integrating, we get the expression of the force F acting on the total surface A of the plate, i.e.,

$$F = \frac{P}{v} = \frac{P}{v}\left(\frac{c}{c}\right) = \frac{P}{c}\left(\frac{c}{v}\right) = \frac{P}{c}n_r \quad (5)$$

where P is the power absorbed by the plate. Thus, the forces F_{g1} and F_{g2}, acting on the plates R1 and R2 of the Shawyer device are expressed by

$$F_{g1} = \frac{P_1}{c}n_{r1} \quad and \quad F_{g2} = \frac{P_2}{c}n_{r2} \quad (6)$$

where P_1 and P_2 are respectively the *powers absorbed by the plates* R1 and R2; n_{r1} and n_{r2} are respectively the indexes of refraction of the plates R1 and R2. Therefore, the expression of the thrust $T = F_{g1} - F_{g2}$, is given by

$$T = \frac{P_1}{c}n_{r1} - \frac{P_2}{c}n_{r2} \quad (7)$$

If $n_{r1} = n_{r2}$, then the equation above can be rewritten as follows

$$T = \frac{P_1 n_{r1}}{c}\left(1 - \frac{P_2}{P_1}\right) \quad (8)$$

If $A_1 >> A_2$ (particular case of Shawyer's thruster) the power P_1 incident on A_1 is much greater than the power P_2 incident on A_2. Then, $P_2/P_1 << 1$. In this case, Eq. (8) reduces to

$$T \cong \frac{n_{r1}P_1}{c} \quad (9)$$

From Electrodynamics we know that when an electromagnetic wave with frequency f and velocity c incides on a flat plate with relative permittivity ε_r, relative magnetic permeability μ_r and electrical conductivity σ, its *velocity is reduced* to $v = c/n_r$ where n_r is the index of refraction of the material, which is given by [3]

$$n_r = \frac{c}{v} = \sqrt{\frac{\varepsilon_r \mu_r}{2}\left(\sqrt{1 + (\sigma/\omega\varepsilon)^2} + 1\right)} \quad (10)$$

If $\sigma >> \omega\varepsilon$, $\omega = 2\pi f$, Eq. (10) reduces to

$$n_r = \sqrt{\frac{\mu_r \sigma}{4\pi\varepsilon_0 f}} \quad (11)$$

Thus, if the plate R1 is made of Copper ($\mu_r = 1, \sigma = 5.8\times10^7 S/m$ [4]), then for $f = 2.54GHz$, Eq. (11) gives

$$n_{r1} \cong 1.4\times10^4 \quad (12)$$

By substitution of this value into Eq. (9), we get

$$T \cong 4.6\times10^{-5} P_1 \quad (13)$$

In the *Shawyer experiment* the total power produced by the magnetron is $P_0 = 850W$. Part of this power is absorbed by the waveguide, and by the plate R2 (plate with lower area). Assuming that the remaining power is about 40%-50% of P_0, then the power radiation absorbed by the plate R1 is $P_1 \cong 400W$. By substitution of this value into Eq. (13), we obtain a theoretical thrust out put of $T \cong 18mN$, which is in close agreement with the thrust measured in the Shawyer experiment.

Now, if the plate R1 is made of a magnetic material with *ultrahigh magnetic permeability*, for example *Metglas* ® 2714A Magnetic Alloy, which has $\mu_r = 1{,}000{,}000$ [5], then Eq. (11) tells us that $n_{r1} \cong 1.4\times10^7$. If $n_{r1} >> n_{r2}$ and $P_1 >> P_2$ then Eq. (7) gives

$$T \cong \frac{n_{r1}P_1}{c} \cong 4.6\times10^{-2} P_1 \cong 18 \quad N \quad (13)$$

This result shows an increasing of about 1,000 times in the thrust of Shawyer's thruster.

It is known that Pulse-modulated Radar Systems can radiate high power of microwaves during short time intervals (pulses), each pulse being followed by a relatively long resting period during which the transmitter is switched off. Usually the pulses are of $1\mu s$ and the pulse repetition time of 1,250 μs. These systems can radiate about 10^6 watts (or more) at each pulse. However, the average power of the radar, due to the time interval of 1,250 μs, is only *some hundreds of watts*. Pulse-modulated Radar Systems operating in the range of *GHz* are currently in use. This means that it is possible to provide the Shawyer's Thruster with a microwave source similar to those existing in these systems in order to produce radiation pulses with power of about 1 *megawatt* and frequency of 2.54 *GHz*. Thus, by using this microwave source and *Metglas* ® 2714A, the thrust, according to Eq. (13), would be of the order of 10,000 *N*. If the microwave source radiates pulses with 10 megawatts power then the thrust can reach up to 100kN.

In order to understand the Shawyer's Thruster it is necessary to accept the existence of the *Quantum Vacuum*, predicted by the Quantum Electrodynamics (QED). The free space is not empty, but filled with *virtual* particles. This is called the Quantum Vacuum. When a radiation propagates through it the radiation exerts on the Quantum Vacuum a force (due to the *momentum* carried out by radiation), in the opposite direction to the direction of propagation of the radiation. Based on this fact, we show in Fig. (2), how Shawyer's Thruster works, and why its thrust can be strongly increased by strongly increasing the index of refraction of the plate with the largest area.

Now, we will consider an apparent discrepancy between the expression of the *momentum* derived by Minkowski [6] and the expression derived by Abraham [7]. While Minkowski's *momentum* is directly proportional to the refractive index of the medium, Abraham's momentum possesses inverse proportionality.

From Electrodynamics we know that the expression of the *momentum*, q, is given by [8]

$$q=\frac{\mathcal{E}\,v}{c^2}=\frac{\mathcal{E}}{c\left(\frac{c}{v}\right)}=\frac{\mathcal{E}}{c}\left(\frac{1}{n_r}\right) \qquad (14)$$

where $\mathcal{E}$ is the *total energy* of the particle.

Note that the expression of the *momentum* given by Eq. (14) is *inversely proportional to the refractive index of the medium* (n_r). However, starting from Eq. (5), we obtain, the following expression for the *momentum*:

$$q=\frac{U}{v}=\frac{U}{c}n_r \qquad (15)$$

which is *directly proportional to the refractive index of the medium* (n_r). However, U is different of $\mathcal{E}$; U is the *absorbed energy*, which transformed into kinetic energy. Thus, the correlation between $\mathcal{E}$ and U is given by $\mathcal{E}=\mathcal{E}_0+U$, where $\mathcal{E}_0=m_0c^2$ is the *rest* inertial energy of the particle, and $\mathcal{E}=m_0c^2\big/\sqrt{1-v^2/c^2}=\mathcal{E}_0\big/\sqrt{1-v^2/c^2}$. Then, we can write that

$$U=\mathcal{E}\left(1-\sqrt{1-v^2/c^2}\right) \qquad (16)$$

For $v<<c$ we have $\sqrt{1-v^2/c^2}\cong 1-v^2/2c^2$. Thus, Eq. (16) can be rewritten in the following form

$$U=\mathcal{E}\left(v^2/2c^2\right) \qquad (17)$$

whence we obtain

$$\frac{2U}{v}=\frac{\mathcal{E}\,v}{c^2} \qquad (18)$$

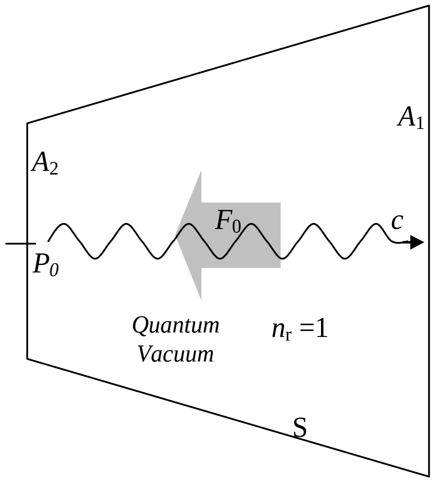
Note that the term $\mathcal{E}v/c^2$ is exactly the expression of the momentum q (See Eq. (14)). Thus, we can write that

$$q=\frac{2U}{v} \qquad (total\quad reflection) \qquad (19)$$

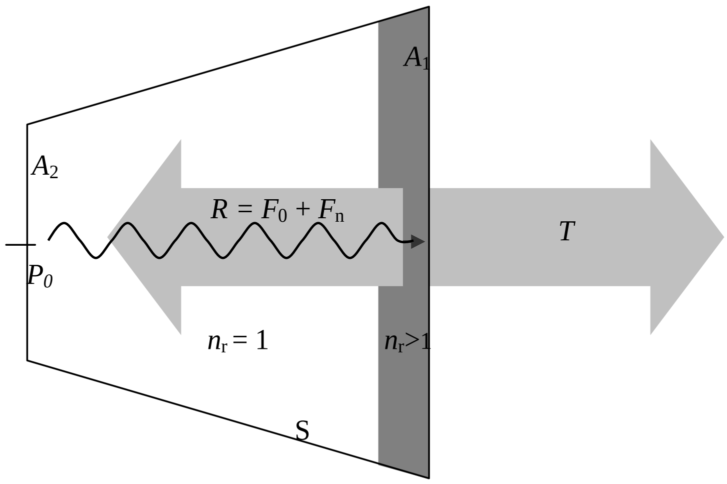
and therefore,

$$q=\frac{U}{v} \qquad (total\quad absorption) \qquad (20)$$

This equation, as we have already seen, leads to Eq. (15). Thus, the correlation between $\mathcal{E}$ and U (Eq. 16), clarifies the expression of the *momentum*, i.e., the *momentum* as a function of the absorbed energy, which is transformed into kinetic energy, U, is *directly proportional to the refractive index of the medium*, n_r, while the *momentum* as a function of the total energy of the particle, E, is *inversely proportional to the refractive index of the medium*, n_r.



(a)



(b)

Fig.2 – *Quantum Thruster*. Figure 2(a) shows that, when a radiation with power P_0, emitted from the System S, propagates through it, from A_2 to A_1, with velocity c, the radiation exerts on the *Quantum Vacuum* a force $F_0 = P_0 / c$ (due to the *momentum* carried out by radiation), in the opposite direction to the direction of propagation of the radiation. Figure 2(b) shows that, if inside the system S there is a region with index of refraction great than 1, then, when the radiation passes through this region it velocity is reduced to $v = c/n_r$, where n_r is the index of refraction of the region. Consequently, the radiation exerts on the Quantum Vacuum a force $F_n = P_0 / v$, which is greater than F_0. Thus, in this case, the total force exerted on the Quantum Vacuum in the direction from A_1 to A_2 is $R = F_0 + F_n$. On the other hand, according to the *action reaction principle*, the system S is propelled with a force T (equal and opposite to R). Thus, if $n_r >> 1$ then $F_n >> F_0$. Consequently, $T = R \cong F_n$.

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