Optimisation of a quantum pair space thruster

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Abstract: *The paper addresses the problem of propulsion for long term space missions. Traditionally a space propulsion unit has a propellant mass which is ejected trough a nozzle to generate thrust; this is also the case with inert gases energized by an on-board power unit. Unconventional methods for propulsion include high energy LASERs that rely on the momentum of photons to generate thrust. Anti-matter has also been proposed for energy storage. Although the momentum of ejected gas is significantly higher, the LASER propulsion offers the perspective of unlimited operational time – provided there is a power source. The paper will propose the use of the quantum pair formation for generating a working mass, this is different than conventional anti-matter thrusters since the material particles generated are used as propellant not as energy storage.*

Two methods will be compared: LASER and positron-electron, quantum pair formation. The latter will be shown to offer better momentum above certain energy levels.

For the demonstrations an analytical solution is obtained and provided in the form of various coefficients. The implications are, for now, theoretical however the practicality of an optimized thruster using such particles is not to be neglected for long term space missions.

Key Words: *quantum pair, LASER thruster, space propulsion, unconventional methods*

Nomenclature

c= velocity of light in the vacuum

k=0.8708 trade-off coefficient for quantum pair-LASER thrusters

$v_k = 0.8708 \cdot c =$ the velocity at which photonic momentum equals the quantum pairs momentum (for the same total energy)

p_e = momentum of the relativistic particle pair

p_ϑ = momentum of the photon

E_{total_e} = total energy of the relativistic particle pair

E_ϑ = total energy of the photon

n = the number of considered particles

v_2= equivalent velocity at which the momentum of one relativistic particles equals the momentum of n relativistic particles having the v_k velocity

$q = \dfrac{v_1}{c\sqrt{1-\frac{v_1^2}{c^2}}} = 1.771224$ = relativistic coefficient

$\dfrac{v_2}{c} = a$ = equivalent velocity to speed of light ratio

p_1 = total momentum of the n particles at v_k velocity

p_2 = momentum of the relativistic particle at v_2 velocity

W_1 = total energy of the n particles at v_k velocity

W_2 = total energy of the relativistic particle at v_2 velocity

$v_m = 0.9985 \cdot c$ =optimal velocity for maximum momentum obtainable with no rest mass propellant

υ_{e+e-} = The frequency at which a pair of two photons would reach equal momentum to a positron-electron pair at v_m velocity

1. INTRODUCTION

Virtually all propulsion systems rely on the principle of reaction, i.e. the ejection of high speed fluids, particles or photons in order to provide thrust. The main advantage of a LASER propulsion system is the almost unlimited operational time, the only requirement being that there is some power source. However this system will generate modest thrust forces compared to gas propulsion units hence it is not favored for space missions.

It is the purpose of this paper to theorize a novel propulsion principle which relies on relativistic principles to obtain better results than the ones possible with any LASER technology. The state of the art is well presented in Ref. [1], LASER propulsion units' development is discussed in Ref [2].

It is a consequence of the quantum theory that if a high energy photon passes trough the field of a large atom, it will generate a quantum pair of mater and anti-mater. This phenomenon is named "quantum pair formation"; Ref [3] offers a mathematical model on quantum pair formation.

Thus far, anti-mater has been proposed for space propulsion but only in the form of energy storage, Ref [4]; however the proposed system uses the anti-mater as work-fluid rather than energy storage. Although quantum pair formation can be obtained trough various methods, Ref [5] trough [8], we will only focus on the high energy photon quantum pair formation.

Various technical aspects mentioned here include high energy LASERS, charged particle accelerators and electromagnetic nozzles, similar to those described in Ref [9], Ref [10] and Ref [11], respectively.

This paper will show that high energy quantum pairs generated by LASER photons can provide higher momentum for the same energy level, hence offering a theoretical improvement on the current state of the art. A schematic of the envisioned system is presented in Fig.1. The system consists of a high energy LASER that fires a beam of photons trough a chamber containing heavy gas particles in order to generate the positron-electron pair. The chamber is at all times subject to a perpendicular magnetic field which causes the two opposite charged particles to deviate in opposite directions. After capturing the two particles we can guide them, further using magnetic fields and inject them into a particle accelerator. In this case we chose the betatron as it does not have the synchronization issues encountered in synchrocyclotrons, making it ideal for accelerating particles from very low velocities to very high, relativistic velocities. After reaching the desired optimal velocity in the particle accelerators, the particles are exhausted via two magnetic nozzles in order to generate thrust.

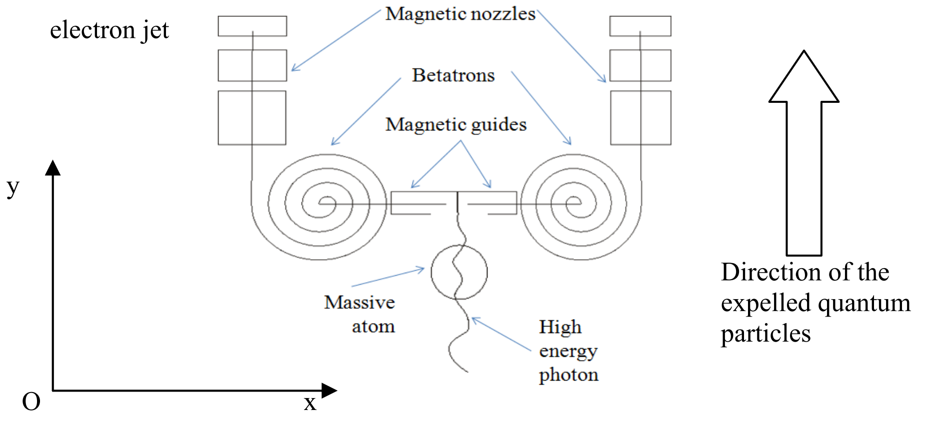

Fig.1 The generic layout of the proposed propulsion system

2. THE EFFICIENCY THRESHOLDS

The following demonstration has a similar variation which is presented in Ref [15]; Firstly, the equations for momentum are written:

$$p_e = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1}$$

$$p_\vartheta = \frac{h\upsilon}{c} \tag{2}$$

Then follow the equations for total energy, in which we will only factor in the kinetic energy and the equivalent energy to the rest mass of the particles (the various energy losses associated with the practical quantum pair generation being left out):

$$E_{total\_e} = m_0 c^2 + \frac{m_0 v^2}{2\sqrt{1-\frac{v^2}{c^2}}} \tag{3}$$

$$E_\vartheta = h\upsilon \tag{4}$$

The Energy to Momentum Ratios:

$$\frac{E_{total\_e}}{p_e} = m_0 c^2 \cdot \frac{\sqrt{1-\frac{v^2}{c^2}}}{m_0 v} + \frac{m_0 v^2}{2\sqrt{1-\frac{v^2}{c^2}}} \cdot \frac{\sqrt{1-\frac{v^2}{c^2}}}{m_0 v} = c^2 \frac{\sqrt{1-\frac{v^2}{c^2}}}{v} + \frac{v}{2} \tag{5}$$

$$\frac{E_\vartheta}{p_\vartheta} = h\upsilon \cdot \frac{c}{h\upsilon} = c \tag{6}$$

We name k as the ratio *v/c*, and by equalizing the two ratios, the following /can be written:

$$c = c^2 \frac{\sqrt{1-\frac{v^2}{c^2}}}{v} + \frac{v}{2} \tag{7}$$

that can be expressed:

$$0 = c \frac{\sqrt{1-\frac{v^2}{c^2}}}{v} + \frac{v}{2c} - 1 \tag{8}$$

Or,

$$\frac{\sqrt{1-k^2}}{k} + \frac{k}{2} - 1 = 0 \tag{9}$$

This four degree equation has only one real and positive root, which is lower than 1:

k=0.8708

Therefore, the velocity at which the proposed space thruster becomes more efficient than a LASER is:

$$v_k = 0.8708 \cdot c$$

Thus, for exhaust velocities greater than 0.8708 c, it is more energy efficient to use corpuscular propulsion rather than photonic propulsion.

3. OPTIMISATION OF THE ENERGY TO MOMENTUM RATIO

Further analysis of the concept has been made to investigate a reasonable peak in such corpuscular propulsion efficiency. Because the energy to momentum ratio was not enough, a different approach has been made:

Given a certain momentum, would it be more energy consuming to have one high energy particle exhausted or more particles at the exact limit velocity of 0.8708c?

Writing the momentum equations for the two cases:

$$p_1 = \frac{m_0 v_k}{\sqrt{1-\frac{v_k^2}{c^2}}} \cdot n \tag{10}$$

$$p_2 = \frac{m_0 v_2}{\sqrt{1-\frac{v_2^2}{c^2}}} \tag{11}$$

We divide both by the rest mass of the particles and the speed of light:

$$p_1 = \frac{v_k}{\sqrt{1-\frac{v_k^2}{c^2}}} \cdot \frac{n}{c} \tag{12}$$

$$p_2 = \frac{v_2}{c\sqrt{1-\frac{v_2^2}{c^2}}} \tag{13}$$

Since the limit velocity is known we can make the notation, in order to simplify the shape of the equations used for the current demonstration (although the constant q is a direct derivative of the constant *k*):

$$q = \frac{v_k}{c\sqrt{1 - \frac{v_k^2}{c^2}}} \tag{14}$$

And for further simplicity:

$$\frac{v_2}{c} = a \tag{15}$$

We then re-write and equalize the momentum equations

$$p_1 = q \cdot n = p_2 = \frac{a}{\sqrt{1 - a^2}} \tag{16}$$

Leading to the equation:

$$a^2 = \frac{q \cdot n}{1 + q^2 \cdot n^2} \tag{17}$$

And hence,

$$v_2^2 = \frac{q^2 \cdot n^2}{1 + q^2 \cdot n^2} \cdot c^2 \tag{18}$$

Moving on to the energy equations we can compare the two cases

$$W_1 = n \cdot \left(m_0 c^2 + \frac{m_0 v_k^2}{2\sqrt{1 - \frac{v_k^2}{c^2}}} \right) \tag{19}$$

$$W_2 = c^2 \left(1 + \frac{q^2 \cdot n^2}{1 + q^2 \cdot n^2} \cdot \frac{\sqrt{1 + q^2 \cdot n^2}}{2} \right) \tag{20}$$

The calculated value of q is the non-dimensional constant: $q = 1.771224$

Also it should be noted that all values of n should be higher than one, in order for the equations to have physical meaning.

The only value for which both $p_1 = p_2$ and W_1 equals W_2 is when: $n = 5.21198$

The interpretation of this is that the maximum velocity we can *economically* choose to accelerate the expelled particles should correspond to a momentum 5.2 times greater than the momentum of a particle at the limit velocity v_k.

$$p_1 = \frac{m_0 v_k}{\sqrt{1 - \frac{v_k^2}{c^2}}} \cdot n = p_2 = \frac{m_0 v_2}{\sqrt{1 - \frac{v_2^2}{c^2}}} \tag{21}$$

Leading to the optimal velocity for particle ejection: $v_m = 0.9985 \cdot c$

Table 1 Specific performances of the two thrusters

Propulsion type	Specific Thrust	Relative Energy Consumption (as a ratio to the photonic drive)
Photonic drive	c	1
Positron-electron drive	0.9985 c	0.499

Considering the practical aspects of designing such propulsion systems one has to take into account the energy levels of the photons used. It is needless to say that the higher the energy required per photon, the higher its frequency will be.

Gamma ray photons, the only ones that might achieve similar momenta to the quantum pair drive, cannot be completely channeled and controlled easily. Whereas the quantum pair engine can not only be more easily managed but also less potentially harmful for the inhabitants of the vehicle or its instruments.

The generic idea of the paper refers to a quantum pair engine that generates "cold" particles and then accelerates them inside a betatrone or similar particle accelerator, however, there exists the possibility of generating "hot" particles near the optimal velocity calculated above.

The frequency at which a pair of two photons would reach equal momentum to a positron-electron pair at the limit velocity is:

$$\upsilon_{e+e-} = m_0 c^2 \frac{0.9985}{h\sqrt{1-0.9985^2}} \qquad (22)$$

$$m_0 = 1{,}022 MeV / c^2$$

4. CONCLUSIONS

The paper investigates a new principle for space propulsion which involves no on-board working fluid. Furthermore, an optimization of the proposed quantum pair space propulsion systems is elaborated.

The first section proves that, if a certain propulsion particle velocity is achieved, the quantum pair drive is more energy efficient than a photonic drive. The exhaust velocity at which it is more energy efficient to generate quantum pairs for propulsion is $v_k = 0.8708 \cdot c$, at this speed, the total energy of the quantum pair is less than that of the photon that has an equal momentum.

Further development of the quantum pair drive is made by providing an optimal exhaust velocity for maximizing energy efficiency. The velocity was found to be very close to the velocity of light in vacuum: $v_m = 0.9985 \cdot c$.

The section compares the specific performances of the LASER and the quantum pair thruster showing that, although the quantum pair thruster has a slightly lower maximum specific impulse, it more than compensates trough the energy consumption which is half of that of a photon drive.

Finally, some practicality issues are discussed in the closing section including the gamma ray problems associated with a high energy photonic drive and showing how they are avoided by the positron-electron pair space thruster.

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