POYINTING VECTOR - AN APPLICATION FOR DESIGN OF ALTERNATIVE ENGINE UNIT

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Abstract: *This paper is focused on construction design of alternative engine unit of a new type. A fundamental part of its conception stands on the theory of electromagnetic field and relative physical areas. Some physical facts are documented by experiments. Mathematical and physical appendix is presented in the following paper : Force Effect of Poynting Vector.*

Key words: *Electromagnetic (EM) field, vacuum, Poynting vector, force, space technology*

INTRODUCTION

Today's scientific world is facing many attractive challenges. Prospecting journey into deep Universe among others poses in the front of them. There are many technological problems to be solved to reach this ambitious goal. One of them is to design effective source of acceleration force - an engine of new generation. This is main target of aim described in this paper.

The task is to develop an engine unit able to replace classical fossil fuel dependent rocket jets. These today used engines are very complex. They are composed from economically expensive materials. They are containing many movable parts and parts exposed to extreme mechanical and thermal strain. Some functional units have to be doubled or event triplicated to increase reliability. All these facts increase total budget necessary for any space mission. Moreover eliminating heavy fuel tanks will yield additional cargo capacity of the spaceship.

New generation of spaceship engines must be able to work continuously for long time period without possibility of repair, maintenance or even replacement.

No moving parts are desired from the point of view of reliability criterion. Great and extreme temperature changes sustain, vacuum "friendly" function and hard radiation robustness are features required automatically for the mentioned purpose.

1 PROBLEM FORMULATION

The problem which is to be solved in this paper is a proposal of design of alternative engine unit meeting demands briefly sketched in previous introductory paragraph. This problem can be expressed by following list of main necessary features of new engine unit :

Possibility of usage in near Earth conditions as well as in the open Universe which implies independence on concrete environment. It means not only air or gaseous atmosphere but also presence and or absence of gravitation and other fields of various character.

Independence on conventional energy sources for very long time period.

Minimal number of moving parts used in total design to ensure as high reliability as possible.

Maximal usage of today's technology possibilities which means to take into account available level especially of electronics and control technology and also available construction materials.

From modern point of human point of view there is also a demand of "environmental friendly" concept which will not damage the Nature.

2 THEORETICAL BACKGROUND

When designing new engine for deep space mission one has to assume environmental conditions in such a place. Majority of the Universe is filled by vacuum. So such engine must be also consistent with vacuum properties.

Physicists are discovering new amazing facts about vacuum almost daily. What are the main characteristics of vacuum being important for mentioned design target ?

Vacuum is very often considered as an "empty space". In [4] it is mentioned as a space without mass particles. Old Grecian philosopher Democritus (455-370 before Christ) did state an idea of "atoms and emptiness". Also non-physical substances of vacuum can attract our

interest. In children psychology there is very long time know fact that little babies when starting to make their first "art works" are drawing a circle shape. Explanations is simple - circle is one of graphical expressions of zero value. But it is also an expression of completeness or Zodiac - twelve constellations behind projection of Sun journey observed from the Earth. An accident ? Zero is mathematical symbol for "nothing", or by another words for "no value" or for so called neutral element in many algebraic systems, group or ring theory etc. Coincidence with physical explanation of "vacuum" term was already mentioned several rows above.

Are these conceptions really true ? Can they be utilized in physical practice ? Many considerable associations (NASA, CERN, USAF, etc.) put high effort to discover substantial properties of vacuum. The results are showing some unpredictable substances observed also in a results of test nuclei cyclotron trashes.

Vacuum has nonzero value of its permitivity and permeability [3], [1]so it has the matter substance – so what is its structure ? From the available scientific sources of experimental results it can be seen that vacuum has a structure of the time-space foam. An illustrative picture of this structure is in Fig.1. This foam can be seen as a cross-section projection of vacuum structure.
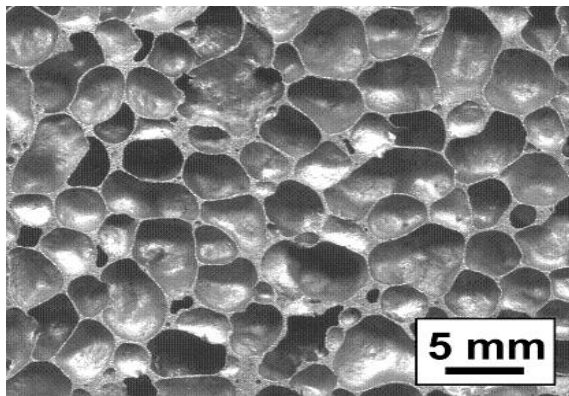

Fig.1:Aluminium foam [8]

It is obvious that a suitable description of the structure of vacuum can help considerably to the solution of the problem. Direct mathematical description leads either to probability models which are not of use here or to very tough vast description.

Basic concept of the theory of EM field recognizes vacuum as an environment which is homogenous, isotropic and linear.

On the other hand vacuum is - from the formal mathematical point of view [5] - carrier of an algebraic structure and then forces and equations can be assumed as n-ary functions and transformation processes are mapping from into this carier. So we are dealing with general algebraic structure.

Here we are to take into account that non-linear character of vacuum implies difficulties of predictions of development of some features. In detail these phenomena are being studied by theoretical physicists and also are in focus of interest of the edge of experimental nuclear research where so called quark-gluon plasma is newly studied [7].

To be complete it is to be added that the facts mentioned above are also a cause of so called chaotic behavior observed as well as in plasma as in vacuum.

All of this is leading to a concept of time-space foam defined originally in quantum mechanics and more discussed here in following paragraphs.

Before describing these terms in more detail we will look on any historical root of the problem of space ship engine.

3 MECHANICAL INSPIRATION

The solution presented in following parts of this paper originated in a mechanical form of this problem.

An initial inspiration can be derived from astronauts practice when working in weightless condition environment. What is a way to turn own body around longitudinal axis ? Simply to start rotate by own hand raised above head. Momentum conservation law causes slow contra-rotation of the body. Well, and now let us imagine a mirroring of this momentum force, let us describe it by suitable set of differential equations and solve it. All this procedure results in parametrical functional description of a mirrored move of a mass body generating accelerating force.

This was realized and proved on a mechanical model the behavior of which was snapped on a several photos several years ago. The pictures are in Fig.2a to 2e. There are phases of continual move of experimental vehicle on a horizontal flat smooth plane. On the photos there is a length mark with length 10 cm (bottom right corner of each photo) to indicate a move of the vehicle. The vehicle itself has two small weights rotating on arms and thus performing mirrored move with non-linear character of speed of angular velocity. Resulting total force did cause waving forward motion (right direction on photos 2a to 2e). The vehicle was powered by small DC engine. Total mechanical effectiveness was slightly less than 2 %. It is not much and moreover there are many moving parts which are decreasing dependability of the whole system however this model proved introductory idea of new engine type in practice.
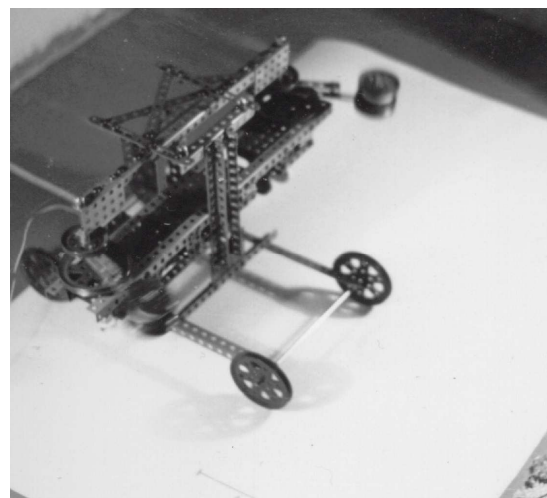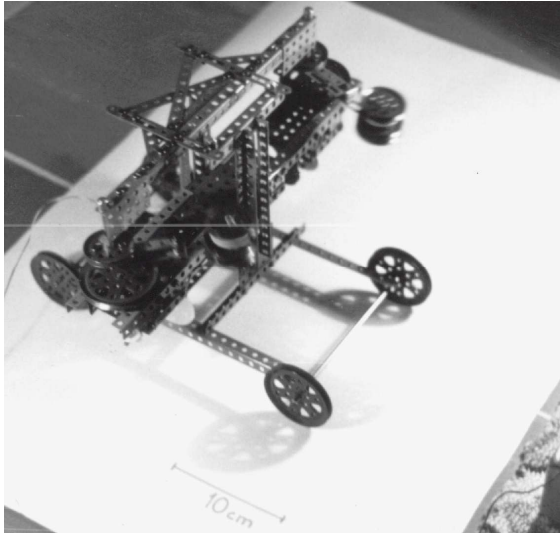

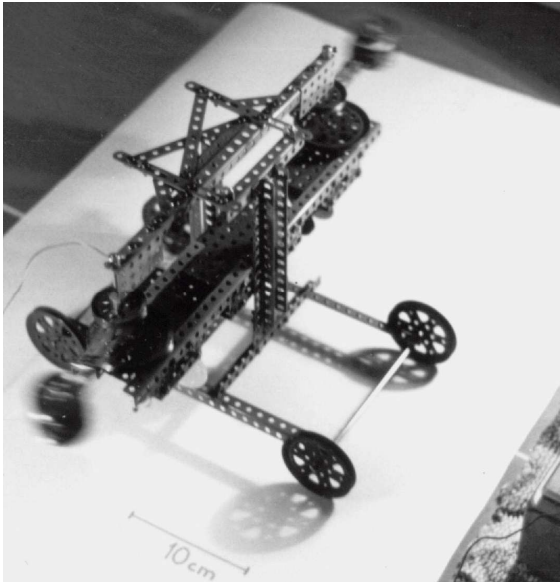Fig.2a : mechanical model

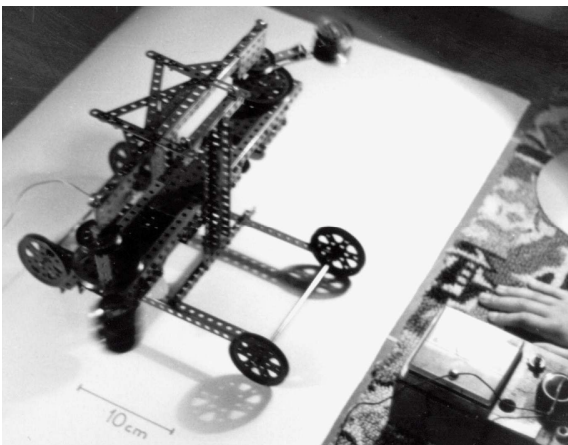Fig.2b : mechanical model

Fig.2c : mechanical model
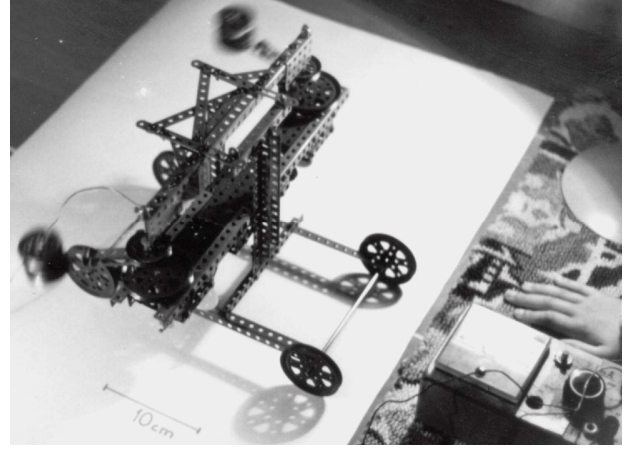

Fig.2d : mechanical model

Fig.2e : mechanical model

Mechanical model did prove the initial idea. Now there arises logical question : what is better physical principle usable to realize the solution of the new engine unit and simultaneously meet preliminary demands ? The answer lies in the theory of electromagnetic (EM) field.

4 FORCE OF POYNTING VECTOR

Poynting vector is defined by well known relation (e.g. [3], [1])

$$\mathbf{S}(t) = \mathbf{E}(t) \times \mathbf{H}(t) \tag{1}$$

Vector $\mathbf{E}(t)$ is the vector of electric field strength. In case of finite dimensional problem can be represented by electric field vector inside a capacitor.

And $\mathbf{H}(t)$ is the vector of magnetic field strength. In case of finite dimensional problem it can be represented by vector of the flux inside a coil.

We want to get directional effect - for the engine will pull in defined direction to minimize losses of emitted energy into side lobes. It can be simply ensured e.g. by choosing of following forms of the vectors :

$$\mathbf{E}(t) = \begin{bmatrix} 0 & E_y(t) & 0 \end{bmatrix} \tag{2}$$

$$\mathbf{H}(t) = \begin{bmatrix} 0 & 0 & H_z(t) \end{bmatrix} \tag{3}$$

Hence this orthogonal choice will give one directional Poynting vector :

$$\mathbf{S}(t) = \begin{bmatrix} E_y(t) \cdot H_z(t) & 0 & 0 \end{bmatrix} \tag{4}$$

Driving force of such engine would be of course this :

$$\mathbf{F}(t) = \begin{bmatrix} F_x(t) & 0 & 0 \end{bmatrix} \tag{5}$$

where (e.g. in [2])

$$F_x(t) = \frac{1}{c^2} \left(\frac{dE_y(t)}{dt} H_z(t) + E_y(t) \frac{dH_z(t)}{dt} \right) \tag{6}$$

Up to this place this solution is not wondering in anything. However now one has to take into account the following facts :

"Classical" approach will lead to known results. Time derivatives in (6) are divided by term c^2 and so they are, especially in case of harmonic signals feeding the engine, yielding too weak force to be used as an acceleration source. Moreover to respect energy conservation law it comes up that mean value of the feeding signals must have zero value. This conception can be compared with operation mode of amplifiers feeding long metallic cables (e.g. transatlantic ones). Possible solution(s) will either not exist or they will be many.

The theory of functional equations seems to be very suitable tool to be used for solution of this problem. One wants to find such time dependent functions $E_y(t)$ and $H_z(t)$ that the following conditions must be simultaneously holding :

$$E_y(t) = E_y(t+T) \qquad (7)$$

$$H_z(t) = H_z(t+T) \qquad (8)$$

$$0 = \int_0^u E_y(t) H_z(t)\, dt \qquad (9)$$

where

$$u \to +\infty \qquad (10)$$

(in special case $u = T$)
and finally :

$$G(u) = \int_0^u F_x(t)\, dt \qquad (11)$$

with strict demand :

$$G(u) > 0 \qquad (12)$$

Physical meaning of the relations mentioned above are following :

(7) and (8) express periodicity of $E_y(t)$ and $H_z(t)$,

(9) with condition (10) express demand on physical real values of $E_y(t)$ and $H_z(t)$.

(11) and (12) describe accelerating effect of the engine and state basic problem to be maximized over all elements having any influence on $F_x(t)$.

5 SOLUTION DESIGN AND SIMULATION RESULTS

Basic question is construction design of the engine. As mentioned above its main function is to emit energy of EM field represented by Poynting vector in one defined direction.

Antenna's theory, see e.g.[6], offers good approach to this case. If one will consider electric field emitter as a dipole and magnetic field emitter as a loop we will get a structure like shown in Fig.3. It is round shape loop with the dipole placed inside it.
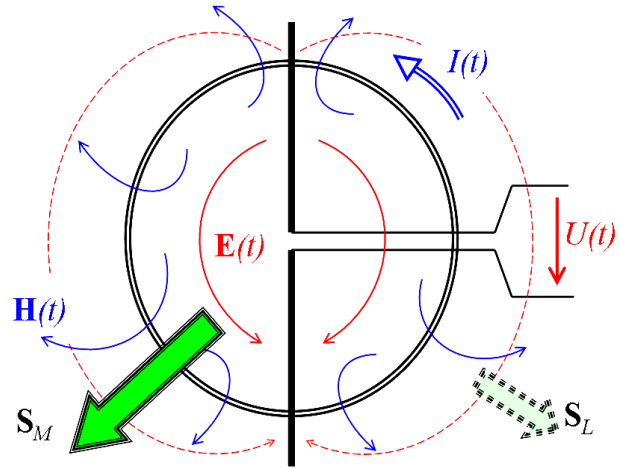

Fig.3: "Dipole and circular loop" structure

In Fig.3 are these objects :
$U(t)$ is voltage feeding the dipole.
$\mathbf{E}(t)$ is electric field strength vector.
$I(t)$ is current in the coil loop.
$\mathbf{H}(t)$ is magnetic field strength vector.
$\mathbf{S}_M$ is "main" Poynting vector generated by cross product of $\mathbf{E}(t)$ and $\mathbf{H}(t)$ in an area inside the loop.
$\mathbf{S}_L$ is "loss" Poynting vector originating from cross product of $\mathbf{E}(t)$ and $\mathbf{H}(t)$ in an area outside the loop where $\mathbf{E}(t)$ and $\mathbf{H}(t)$ have curved space orientation.

One can thus see a chart of principle of the engine but also possible weak feature of this construction. This disadvantage is stronger as length of the dipole is greater than diameter of the loop - which is the case in Fig.3.

One of possible improvements is based on change of shape of the loop and correction of proportions between dipole and loop. Fig.4 shows such change. Here also "loss" Poynting vector exist but volume of the space inside which $\mathbf{S}_L$ is generated is less than volume of the space where $\mathbf{S}$ is generated and so we get higher efficiency.
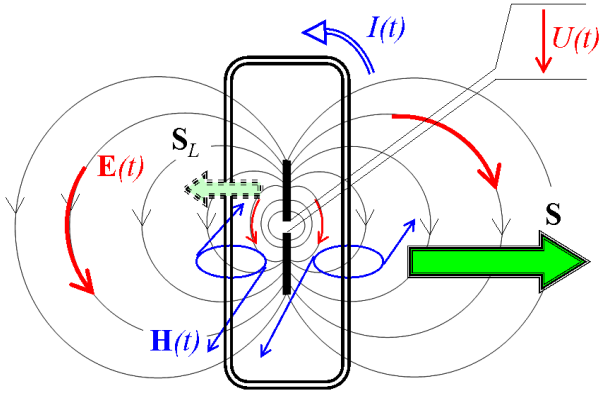
Fig.4: "Dipole and rectangular loop" structure

Many other arrangements and shape forms can be taken into account, as is well known from antenna theory (e.g. in[6]). Here in this paper we will focus mainly on the principle and its proof get by numerical simulation.

From point of view of simple application of calculus of variations, formal solution in form of monotonous ever growing values of $E_y(t)$ and $H_z(t)$ seem to be acceptable solution but they are violating periodicity conditions (7) and (8) and also leads to physically meaningless infinite energy values.

Another natural way of choice of $E_y(t)$ and $H_z(t)$ is the form of a combination of time-harmonic signals. Possible results of such case is in Fig.5. Again no desired result obtained. In Fig.5 there are three graphs showing simulation of feeding signals and resulting behavior of resulting Poynting vector and its time derivative. Left top, bottom resp., graph shows time development of electric, magnetic resp., field strength and hence there are components of feeding signal of the engine. Right polar graph shows Poynting vector derivative with respect to time plotted in module-phase diagram. It is drawn only for x-axis direction in accordance with relation (4).
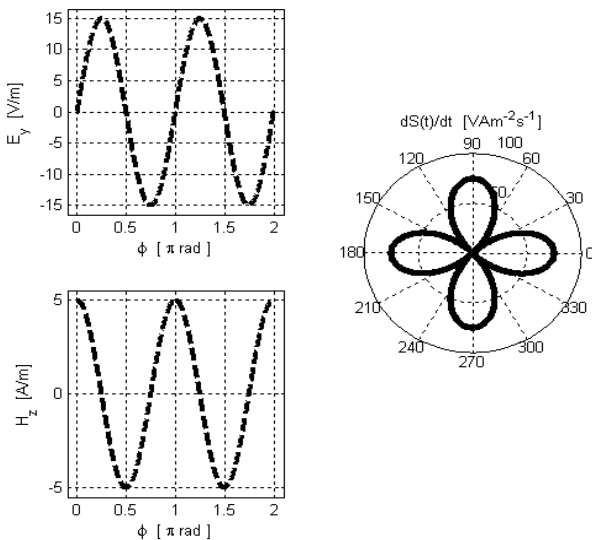

Fig.5: Harmonic feeding signals case

The result is not surprising. This Poynting vector value periodically changes but also its space orientation do so. Hence such feeding of the engine unit would "shake" with the spaceship on initial position place without moving anywhere - simply because the condition (12) was not fulfilled. Moreover from simulation and also from every day technical practice is seen that such force is too weak to be considerable as a source of mechanical acceleration. Maximal approx. value of obtained force in this case is $F_x \approx 8.3 \cdot 10^{-16}$ N .

The mathematical background enabling another - and directionally more effective - solution is discussed in more detail in consecutive paper. Herein we will focuse on simulation results.

Let us assume, summarizing all the knowledge described above, the feeding by non-harmonic time-periodic continuous signal. Construction design arrangement of the engine remains similar to those shown in Fig.4. Simulation results are shown in Fig.6.
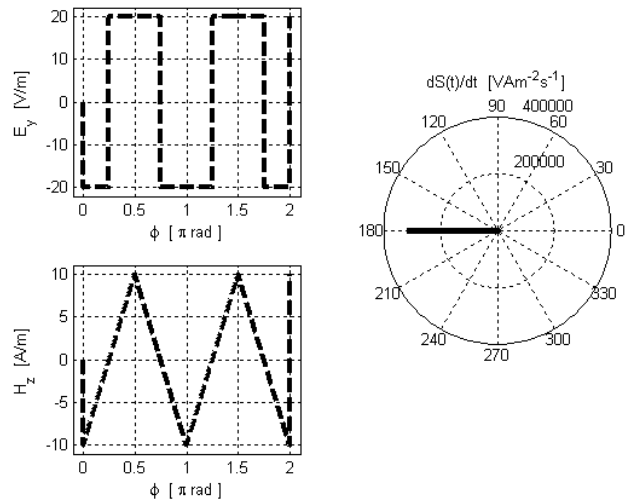

Fig.6: Periodic non-harmonic feeding signals case

In Fig.6 there is $E_y(t)$ time development in left top graph, development of $H_z(t)$ in left bottom graph and time derivative of Poynting $d\mathbf{S}(t)/dt$ vector is drawn in right polar graph where we see strict space concentration of "force beam" emitted by the engine.

Other relevant difference, in comparison to similar graph in Fig. 5, is absolute value of $d\mathbf{S}(t)/dt$ which is obtained thanks to sharp changes of development of feeding signal. Hence in time envelope shape of feeding signal is one of hidden reserves of the construction of such engine.

Concrete formulae describing $E_y(t)$ and $H_z(t)$ are obvious from Fig.6. They are well known rectangular and triangle signals well known from electro engineering.

6 CONCLUSIONS

The problem of design of alternative engine unit for the future generation of space ships was defined, analysed and solved. The preliminary list of demands listed in paragraph **1** was fulfilled. Remaining open questions were discussed; they exceed the extent of this paper and represent the target of the future development aim in this area.

Realization note : all numerical tasks, computer simulations and graphs of results presented in this paper were prepared in MATLAB.

7 ACKNOWLEDGMENTS

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