Propellantless Propulsion by Electromagnetic Inertia Manipulation: Theory and Experiment

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Abstract. One of the challenges to create the Space Drive being to discover a self-contained means of propulsion that requires no propellant, it was already shown that a solution to the problem does exist, provided the system is endowed with tensor mass properties. It is found that under the assumption of Minkowski's Energy-Momentum tensor being the right one (Abraham-Minkowski controversy), the electromagnetic field can modify the inertial properties of the generating device., given suitable charge and current distributions. An experiment to settle the question is then proposed. which consists of mounting the device as a seismic mass atop a mechanical suspension. By supplying a periodic voltage to the coils at a frequency close to the fundamental frequency of the seismic suspension, the expected mechanical effect from inertia variation would cause the fixture to resonate, adding up to the microseismic noise induced vibration. Two series of tests were conducted during the period 1993 - 1997; in practically all cases, the results consistently point to a mechanical vibration induced by matter-electromagnetic field momentum exchange, as predicted by Minkowski's formulation, after all other sources of vibration were taken into account, or removed when possible.

INTRODUCTION

Human interstellar exploration may not be possible without the discovery of a self-contained means of propulsion that requires no propellant (Millis, 1997). This formally translates into the problem of achieving "jet-less" propulsion of spaceships that can then be seen as closed systems, i.e., without external assistance. As already shown (Brito, 1998), a mass tensor is found in connection with the closed system consisting of a rocket driven spaceship and its propellant mass, provided a "solidification" point other than the system center of mass is considered in a relativistic covariant formulation. Accordingly, an alternative propulsion principle, named the Covariant Propulsion Principle (C.P.P.), has been derived from this tensor mass approach, being obviously valid at sub-relativistic velocities and not strictly restricted to the rocket propulsion concept. The new principle reads: A spaceship undergoes a propulsion effect when the whole system mass 4-ellipsoid warps.

Thus a formal solution to the problem exists, provided the system is endowed with tensor mass properties. A further analysis of these properties shows that the propulsion effect is to be related to the deviatoric part of the tensor, which exhibits the particularity of producing a non-vanishing linear momentum in the spaceship comoving Lorentzian frame. This situation is reminiscent of the concept of static electromagnetic (EM) field momentum which can develop in the rest frame of a physical arrangement of electric and magnetic sources including polarizable media, as depicted in Figure 1. Different theoretical results are possible depending whether Planck's principle of inertia of energy is satisfied or not in the relationship between the Poynting vector (energy flow density) and the electromagnetic momentum density (Brevik, 1979). The different determinations are based either on the Planck's principle of inertia of the energy, as being valid within polarizable media, too, or upon a generalization of the Jones and Richards' experimental results about radiation fields within the same media (Joyce, 1975). They are therefore related to the group velocity of electromagnetic waves propagation: that for vacuum in one case; that for matter in the other case, respectively.

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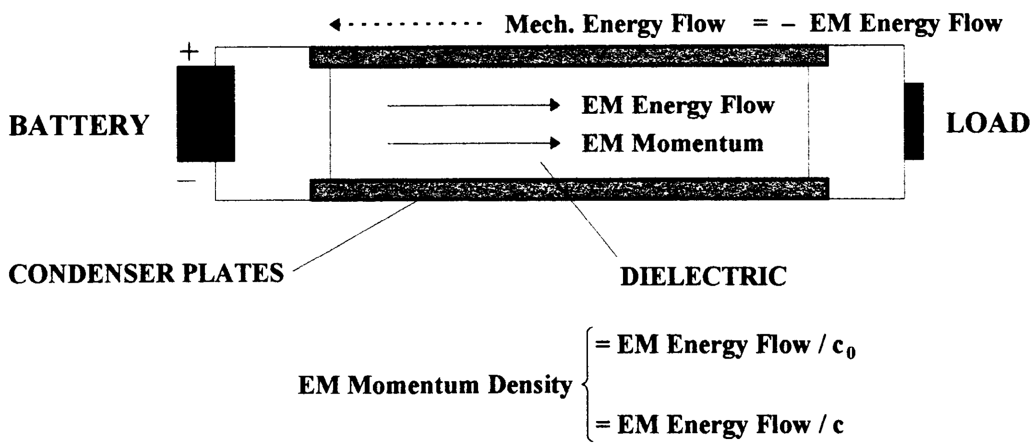

FIGURE 1. Different Determinations of the EM Momentum Density in the "Matter" Rest Frame with Polarizable Media.

The experiment involved real radiation fields; were the same be true concerning the flow of energy in stationary fields, as some forms of the Electromagnetic Field Energy-Momentum tensor seem to suggest (Jackson 1962, Portis 1985, Eu 1986), a non-vanishing momentum of electromagnetic origin would arise in the particular case where some volume is filled with polarizable media. The whole system would then enjoy tensor mass properties of electromagnetic origin, as it happens for a solidification point at rest in the "matter" subsystem frame.

The purpose of this work is to show that, under the assumption of Minkowski's Energy-Momentum tensor being the right one, the EM field, given suitable charge and current distributions, can modify the inertial properties of the generating device, giving rise to the possibility of obtaining mechanical impulses on the device, not undergoing any exchange of mass-energy with the surrounding medium. It is also shown that another wording for the mechanical effects relates them to momenta exchanges between the electromagnetic field and the device's "matter". A propulsion concept based upon this kind of inertia manipulation mechanism is subsequently drawn, the experimental setup built to test that concept is discussed, as well as the obtained results and the applied signal processing techniques.

MASS TENSOR IN THE ELECTROMAGNETIC CASE

The question arises about the general existence conditions of momentum of electromagnetic origin in the "matter" comoving frame. A fully covariant formulation of the problem requires to consider the Energy-Momentum tensors for a closed physical system consisting of "matter" and EM fields. The Law of 4-Momentum Conservation for the particles and fields contained in any four-dimensional region of space-time $\Omega \subset M$ bounded by a closed, three-dimensional surface $\partial\,\Omega$, states that

$$\int_{\partial\Omega} \left(\mathbf{T}^{(m)} + \mathbf{T}^{(f)}\right)\cdot d\Sigma = \mathbf{0}. \qquad (1)$$

If the closed 3-surface $\partial\,\Omega$ is made up of two slices taken at constant time of a specific Lorentz frame, plus timelike surfaces at "infinity" that join the two slices together, and the system of "matter" and EM fields is supposed to be closed in the sens that the surfaces at infinity do not contribute to the integral of Equation (1), this integral gives

$$\frac{d}{dt}\int_{V} \left(\mathbf{T}^{(m)} + \mathbf{T}^{(f)}\right)\cdot \mathbf{u}\, dV = \mathbf{0}. \qquad (2)$$

The system 4-momentum is conserved in time.

Now, if the observer's frame coincides with the frame where the "matter" is at rest when no EM field is present, the condition for anysotropic mass tensor when the EM field is ON, writes down in 4-tensor notation

$$\int_V \left[\left(\mathbf{I} - \mathbf{uu}/c_0^2\right)\cdot\left(\mathbf{T}^{(m)} + \mathbf{T}^{(f)}\right)\cdot\mathbf{u}\right]\wedge\mathbf{u}\,dV \neq \mathbf{0}, \tag{3}$$

therefore

$$\int_V \left[\left(\mathbf{T}^{(m)} + \mathbf{T}^{(f)}\right)\cdot\mathbf{u}\right]\wedge\mathbf{u}\,dV \neq \mathbf{0}, \tag{4}$$

which means that $\mathbf{G}\wedge\mathbf{u} \neq \mathbf{0}$; in no case the system 4-momentum aligns with the observer's 4-velocity.

When consideration is given to the locality of the energy-momentum conservation law, Equation (1) translates into the "differential conservation law" Div ($\mathbf{T}^{(m)} + \mathbf{T}^{(f)}$) = 0, $\forall\mathbf{x} \in M$. Besides, the following relationship can be found for the volume integral of the energy flux (Furry, 1969)

$$\int_V \left(\boldsymbol{s}^{(m)} + \boldsymbol{s}^{(f)}\right) dV = -\int_V \boldsymbol{x}\, div\left(\boldsymbol{s}^{(m)} + \boldsymbol{s}^{(f)}\right) dV. \tag{5}$$

So, for stationary regimes, in any frame

$$\int_V \left(\boldsymbol{s}^{(m)} + \boldsymbol{s}^{(f)}\right) dV = \boldsymbol{0}. \tag{6}$$

Since $\boldsymbol{s}$ represents the spacelike components of the 4-vector $\left(\overline{\mathbf{T}}^{(m)} + \overline{\mathbf{T}}^{(f)}\right)\cdot\mathbf{u}$, for the Equations (4) and (6) being simultaneously true, the whole system energy-momentum tensor must be unsymmetrical.

By splitting the region V in two regions V^+ and V^- such as $\forall\boldsymbol{x}\in V^+,\ \frac{\partial w}{\partial t} \geq 0$; $\forall\boldsymbol{x}\in V^-,\ \frac{\partial w}{\partial t} < 0$, one finds in the case of transient regimes

$$\int_V \left(\boldsymbol{s}^{(m)} + \boldsymbol{s}^{(f)}\right) dV = -\left(\boldsymbol{x}^{*+} - \boldsymbol{x}^{*-}\right)\int_{V^+}\left(\frac{\partial w}{\partial t}\right) dV, \tag{7}$$

where

$$\boldsymbol{x}^{*+} = \frac{\int_{V^+} \boldsymbol{x}\left(\frac{\partial w}{\partial t}\right) dV}{\int_{V^+}\left(\frac{\partial w}{\partial t}\right) dV} \quad ; \text{ and } \quad \boldsymbol{x}^{*-} = \frac{\int_{V^-} \boldsymbol{x}\left(\frac{\partial w}{\partial t}\right) dV}{\int_{V^-}\left(\frac{\partial w}{\partial t}\right) dV}. \tag{8}$$

When the centers of energy density variation rates differ, the left hand side of Equation (7) is non-vanishing and Equation (3) can hold even if the whole system energy-momentum tensor is symmetrical, in which case the total 3-momentum in the "matter" rest frame satisfies

$$\int_V \left(\boldsymbol{g}^{(m)} + \boldsymbol{g}^{(f)}\right) dV = -\frac{1}{c_0}\left(\boldsymbol{x}^{*+} - \boldsymbol{x}^{*-}\right)\int_{V^+}\left(\frac{\partial\left(w^{(m)} + w^{(f)}\right)}{\partial t}\right) dV. \tag{9}$$

The non-vanishing 3-D linear momentum in the rocket comoving Lorentzian frame (Brito, 1998) is just an application of the general Equation (9) to the particular case where all field contributions are absent.

By formal analogy with Equation (5), the right hand side of the spacelike part of Equation (3) can be written

$$\int_V \left(g^{(m)} + g^{(f)}\right) dV = -\int_V x \, div \left(g^{(m)} + g^{(f)}\right) dV . \tag{10}$$

When consideration is given to the relationship between the energy flow and the momentum density, and assuming that the Plank's principle of inertia of the energy does not necessarily hold for the EM energy flux, such as a field of group velocity of electromagnetic waves propagation exists, Equation (10) becomes

$$\int_V \left(g^{(m)} + g^{(f)}\right) dV = -\int_V x \, div \left(\frac{s^{(m)}}{c_0} + \frac{s^{(f)}}{c}\right) dV , \tag{11}$$

or, equivalently

$$\int_V \left(g^{(m)} + g^{(f)}\right) dV = -\int_V \frac{x}{c_0} \left[div \left(s^{(m)} + s^{(f)}\right) + grad\left(\frac{c_0}{c}\right) \cdot s^{(f)} + \left(\frac{c_0}{c} - 1\right) div \, s^{(f)} \right] dV , \tag{12}$$

which, for stationary regimes writes down

$$\int_V \left(g^{(m)} + g^{(f)}\right) dV = -\int_V \frac{x}{c_0} \left[grad\left(\frac{c_0}{c}\right) \cdot s^{(f)} + \left(\frac{c_0}{c} - 1\right) div \, s^{(f)} \right] dV . \tag{13}$$

By taking into account that for such regimes $div\, s^{(f)} = -\, div\, s^{(m)}$, and $g^{(m)} = s^{(m)}/c_0$, Equation (13) finally becomes

$$\int_V g^{(f)} \, dV = -\int_V x \left[grad\left(\frac{1}{c}\right) \cdot s^{(f)} + \left(\frac{1}{c}\right) div \, s^{(f)} \right] dV . \tag{14}$$

The condition of non-vanishing total momentum in the "matter" rest frame is equivalent to the condition of EM momentum being different from minus the mechanical "hidden" momentum. This translates to a non-vanishing EM momentum, since "hidden" mechanical momentum cannot exist for matter alone in stationary regime. The quantity between brackets being $div\, g^{(f)}$, $g^{(f)}$ cannot thus be divergence-free everywhere.

From Equation (13) it can also be seen that tensor mass existence is possible if, and only if, non-homogeneous media are considered. There should be finite regions of polarizable media within the setup for anisotropic mass tensor being possible, provided the Plank's principle of inertia of the energy does not necessarily hold for the EM energy flux. This is the case for the setup shown in Figure 2, where $div\, s^{(f)} = 0$ everywhere and a non-vanishing total EM momentum can only arise from the first term in the right hand side of Equation (14). The contributions for the volume integral come from the free surfaces of the dielectric, through which a jump of the velocity of light takes place in the direction of the EM energy flux, at different locations and with the "right"sign. For this particular setup, transient regimes do not allow to produce an EM momentum contribution since the energy density variation rates distribute symmetrically throughout the setup regions. However, as mentioned previously, the whole system Energy-Momentum tensor is unsymmetrical; this is a rather unconfortable property for a system assumed to be a closed one. Either the assumption that the Planck's principle of inertia of the energy does not hold everywhere is false, or the system is open and one must consider an extended closed system to which the present one belongs.

The first possibility, as far as stationary regimes are considered, precludes completely a closed system to bear a tensor mass; the second possibility leads to the question about what is that extended closed system like. A hint comes from the fact that the "excess" EM momentum behaves as an "external" stress in 4-space.

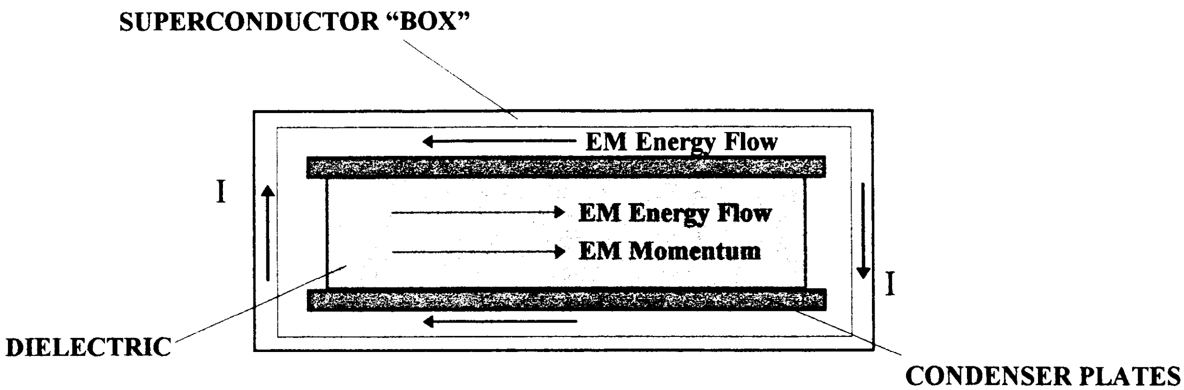

FIGURE 2. Stationary Regime in the "Matter" Rest Frame with Polarizable Media.

As a conjecture, if ZPF (Zero Point Field) were a physical reality for describing inertia (Haisch, 1994), that "excess" EM momentum could be explained as a form of "directed", anisotropic vacuum fluctuations of EM energy. The sought extended system would then happen to be space-time itself.

The existence conditions, when taken separately, are not sufficient to allow for non-vanishing momenta in the "matter" rest frame, with stationary fields. Existence can be achieved when they hold together as it comes out when the Minkowski's Energy-Momentum tensor is used for the EM field (Brevik, 1979), the problem then being whether this combination is physically sound. By the very definition, the Relativistic Mechanics Laws of Conservation are satisfied; the same being true, nevertheless, for the Abraham's Energy-Momentum tensor, together with other forms of the electromagnetic Energy-Momentum tensor (Brevik, 1979). This is precisely the still-standing (Johnson 1994, Antoci 1997) Abraham-Minkowski controversy about the form of that Energy-Momentum tensor, specially for low frequency or quasi-stationary fields (Brevik 1969, Lai 1980, Brevik 1982, Lai 1984). The issue is, as shown, highly relevant to "propellantless" propulsion and experiments to definitely settle the question were still missing besides some partialized attempts (James 1968, Walker 1975, Waker 1977, Lahoz 1979), whose results were not conclusive enough. A positive answer for the Minkowski's EM tensor would allow to obtain "jet-less" propulsive effects by EM fields manipulation, on one hand; on the other hand, it could also represents an indirect demonstration of the physical reality of ZPF, as a possible explanation for unsymmetrical energy-momentum tensors of closed systems.

THRUST BY ELECTROMAGNETIC INERTIA MANIPULATION

The studies about the inertia of the electromagnetic field as something that could be manipulated for propulsion purposes are not new, a tentative explanation was already undertaken on the basis of the relativistic mechanics of extended bodies under electrostatic pressures (Marchal, 1969). However, the C.P.P. allows for a general formulation of the problem, which consists of considering the whole system (Device + EM Field) as a single particle located at the "matter" system c.m. (or any "structural" point) so that a mass tensor is readily found as related to the whole system.

For a closed system ($\mathbf{f} = \mathbf{0}$), provided the electromagnetic field 4-momentum $\mathbf{p}_{EM} \neq \mathbf{0}$,

$$d(\mathbf{M}\cdot\mathbf{v}) = \mathbf{0} \quad \Rightarrow \quad \mathbf{M}\cdot d\mathbf{v} = -\,d\mathbf{M}\cdot\mathbf{v}, \tag{15}$$

where

$$\mathbf{M} = \left(m_0 + m^{*}_{EM}\right)\mathbf{I} + \left(\mathbf{p}_{EM}\wedge\mathbf{v}\right)/\,c_0^2\,. \tag{16}$$

The 4-acceleration of the chosen "solidification point" is written as

$$m_0 \, d\mathbf{v} = -\left(d\mathbf{p}_{EM} \wedge \mathbf{v}\right) \cdot \mathbf{v} / c_0^2 . \quad (17)$$

Thus, the 4-thrust on the single particle, in any arbitrary frame, becomes

$$\mathbf{F} = -\frac{d\mathbf{p}_{EM}}{d\tau} . \quad (18)$$

Equation (18) expresses, as expected, the law of conservation of the total system energy-momentum, consistently with Equation (2). The change of the mechanical (matter) momentum equals the change of the electromagnetic field momentum with opposite sign; momentum is then being exchanged within the whole system.

A propulsion concept based upon this kind of inertia manipulation mechanism can subsequently be drawn, which consists basically of suitably grouping the sources of electric and magnetic fields into a physically connecting device so that a stationary Minkowski's electromagnetic field momentum can be built up thanks to the dielectric filled region (non-homogeneous polarizable media), as depicted in Figure 3; by controlling the intensities of these fields, the inertia properties of the system as a whole, when represented by its "matter" part – the device –, are allowed to change so that a conversion of the EM field momentum into mechanical momentum of the device is expected to happen, and reciprocally, again if Minkowski is right. It can be seen that this device works as an electromagnetic momentum "accumulator". The mechanical momentum that can be drawn from is, within the framework of present Physics paradigms, limited to the "accumulated" amount.

EXPERIMENT AND RESULTS

An electromagnetic momentum generator (EMMG), based on the schematics of Figure 3, was engineered up to the "proof of concept" level and an experiment was designed aimed to verify that: a) The Minkowski's Electromagnetic Energy-Momentum tensor does describe properly the electromagnetic field-matter interactions in polarizable media. b) Global electromagnetic momentum in the matter rest frame of a closed system is being generated, or, equivalently for such a system, a non scalar 4-mass tensor behaviour is being obtained. c) The experimental thruster is applying mechanical forces on the test stand without expenditure of mass, besides that equivalent to the radiant energy dissipated from the system (e.g., Joule heating), which cannot account for the observed effects.

An experimental setup was accordingly built up which consists of mounting the device as a seismic mass atop a mechanical suspension. A supply of 6 A - AC (square wave) to the coils and 4 kV - DC to the capacitors allows for a total electromagnetic momentum (Minkowski's formulation) around 1.E-8 Ns (square wave), by using $BaTiO_3$ ceramic dielectrics.

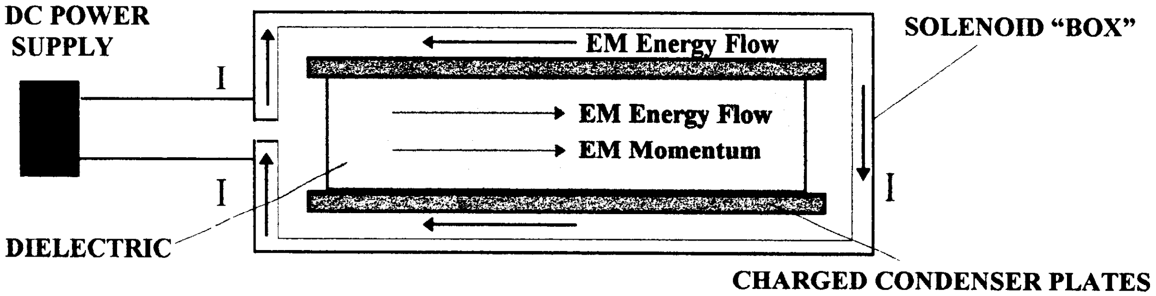

FIGURE 3. Electromagnetic Momentum Generator Schematics .

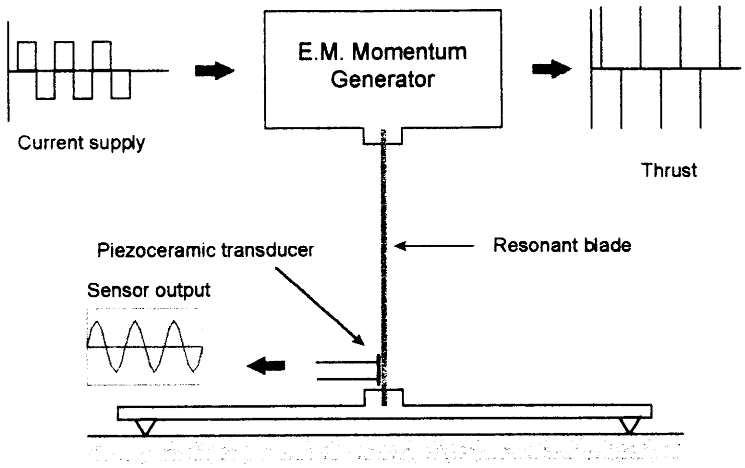

FIGURE 4. Micromotion Sensing Concept.

The alleged conversion of Minkowski's electromagnetic momentum into mechanical momentum of the EMMG gives rise to the creation of dynamic effects - forces- acting upon this device. By means of a square wave activation of the device at a frequency close to the fundamental frequency of the seismic suspension, the supporting blade of the test fixture can be made to resonate so an amplified upper end displacement response is obtained. Displacements in the range 10^{-8} - 10^{-7} m were to be expected; a problem of micromotion detection was then readily identified. To detect this range of displacements, the use of piezoceramic strain transducers was devised, taking into account technological as well as financial constraints. This kind of transducers which outputs electric signals proportional to the strain level in a broad dynamic range, are able to achieve sensitivities of up to 10^{-11} m/m (seismic and acoustic threshold in controlled environments) (Forward, 1980). This is two orders of magnitude lower than the expected levels, as related to the sensing fixture shown in Figure 4. However, The full signal contains a significant amount of ground and environment induced noise as already observed in preliminary testing.

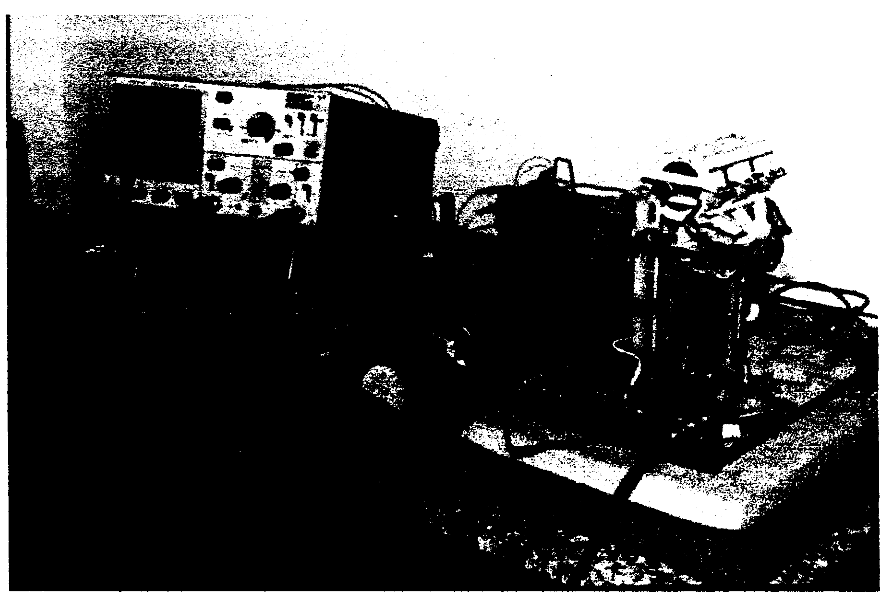

FIGURE 5. Test Equipment.

This microseismic excitation can account for displacements comparable to those expected to be caused by the investigated effect, with a narrow band frequency response centered in the first natural frequency of the sensing fixture. Another source of unwanted noise is the residual interaction between the coils and the Earth magnetic field, which can account for equally comparable total displacements, albeit with a deterministic distribution in the frequency domain. A third source of noise relates to the magnetic interaction between the moving and the fixed parts of the AC and DC circuits (self magnetic interaction), those belonging to the device atop the resonant blade and to the external power supply, respectively. This kind of noise also has a deterministic distribution in the frequency domain, bearing the particularity of presenting the first spectral line at twice the coil activation frequency. It was also found to contribute to the displacements on practically the same foot than the former two mentioned sources. Other sources of noise have been considered, too, like air motion, electrostatic couplings, sound, radiometric effects, spherics, etc, which can have a degrading effect on the measurements quality, although to a lesser amount than the forementioned sources. The overall estimated effect amounts to -60 dB < S/N < -40 dB at the transducer output and the need for further processing arises. To this aim, the analog transducer output signal is converted to digital through a 12 Bit data acquisition board and stored in fixed and portable magnetic support. Digital signal processing techniques are devised for estimation of the deterministic part of the signal which is related to the ponderomotive effects under scrutiny.

Two series of tests were already conducted during the period 1993 - 1997. For the first series of tests, only one measurement channel was available and there was no vibration-free fixtures. The second series of tests included, besides the main transducer measurement channel, a dummy seismic fixture with an ancillary transducer and its measurement channel, a supply voltage measurement channel, and a vibration-free table; the complete test equipment is shown in Figure 5. In both series, the test philosophy was primarily based upon comparison of results in the frequency domain (use of spectral analysis), due to different excitation schemes. These were: A) Ground induced noise. B) Coils ON, capacitors OFF + (A). C) Coils ON, capacitors ON + (A). D) Coils OFF, capacitors ON + (A). Following modeling and simulation activities, geomagnetic and self-magnetic interaction noises were expected to appear in (B) and (C) as compared to (A), while the influence of the capacitors must appear in (C) as compared to (B) if thrust by inertia manipulation is acting upon the device; no difference was expected to arise beween (D) and (A), since static electric fields alone cannot account for the vibratory behavior of the sensing fixture. Results corresponding to the first test series are shown in Figure 6 where, as expected, differences can be observed between the (A) and (B) spectra, mainly caused by geomagnetic noise.

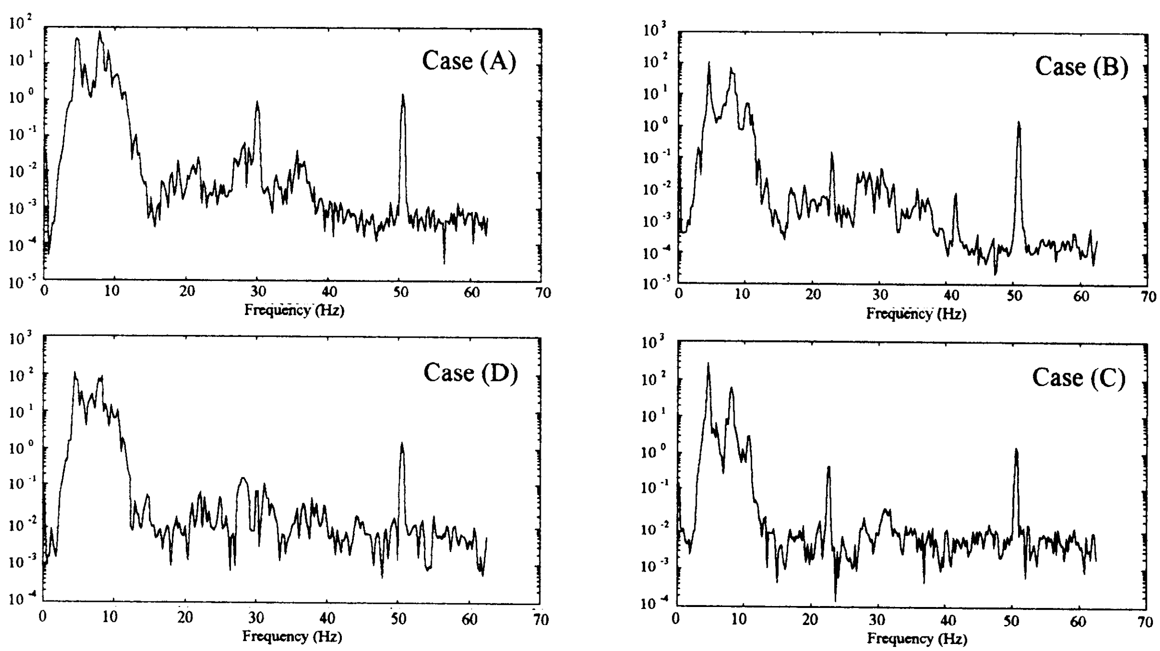

FIGURE 6. PSD of the First Test Series Results - [V^2/Hz].

Differences can also be observed between the (A) and (C) spectra, but there are intriguing differences between the (B) and (C) spectra, while again, as expected, no difference appears between the (A) and (D) spectra. In every case, data was acquired in 5000 samples sequences at a rate of 500 samples/sec. Power Spectral Density (PSD) was estimated over a 2048 length frequency interval, using Welch's averaged periodogram method.

Since a significant amount of ground induced noise was observed during the first test series, it was decided to perform a second test series with the setup improvements as mentioned before. It was also decided to proceed to intensive signal processing so as to achieve a higher confidence in the EMIM (ElectroMagnetic Inertia Manipulation) effect detection.

The experimental data gathered during the second series of tests, according to the forementioned sampling characteristics, were firstly processed to carry on a system identification on the basis of the ground motion excitation only, an ARMA (Auto Regressive Moving Average) model structure being then identified; later, inverse filtering was performed for every output sequence in order to obtain the equivalent ground motion; then, filtering by the vibration isolation fixture led to the reconstruction of the sensing device base motion; finally, optimal filtering (Wiener filter) was performed on the resultant ouput, using the EMMG induced excitation as the "desired" signal.

The raw data exhibit, when presented in the frequency domain, nearly the same pattern as those of the first test series. However, they show, after processing, a more accurate spectral structure as related to the sought excitation spectrum which consists of equal amplitude odd harmonics of the square wave fundamental frequency, as shown in Figure 7. Spectrum (A) contains low level residuals induced by the Wiener filter - a sort of numerical artifact - as well as Spectrum(D); Spectrum (B) does not match the "message" spectrum, it better fits that of the geomagnetic noise square wave excitation; Spectrum (C) shows a structure which strongly suggests an alternate impulsive excitation, as it turn out to be when a square wave EM field-matter momenta exchange is present. The figures are representative of around 16 sequences by case. Better detectability can be obtained by means of statistical analysis over the whole ensembles and by using adaptive noise cancellation procedures, either on the raw output data or on the inverse filtered output data. These activities are presently being carried on and no final results are available yet.

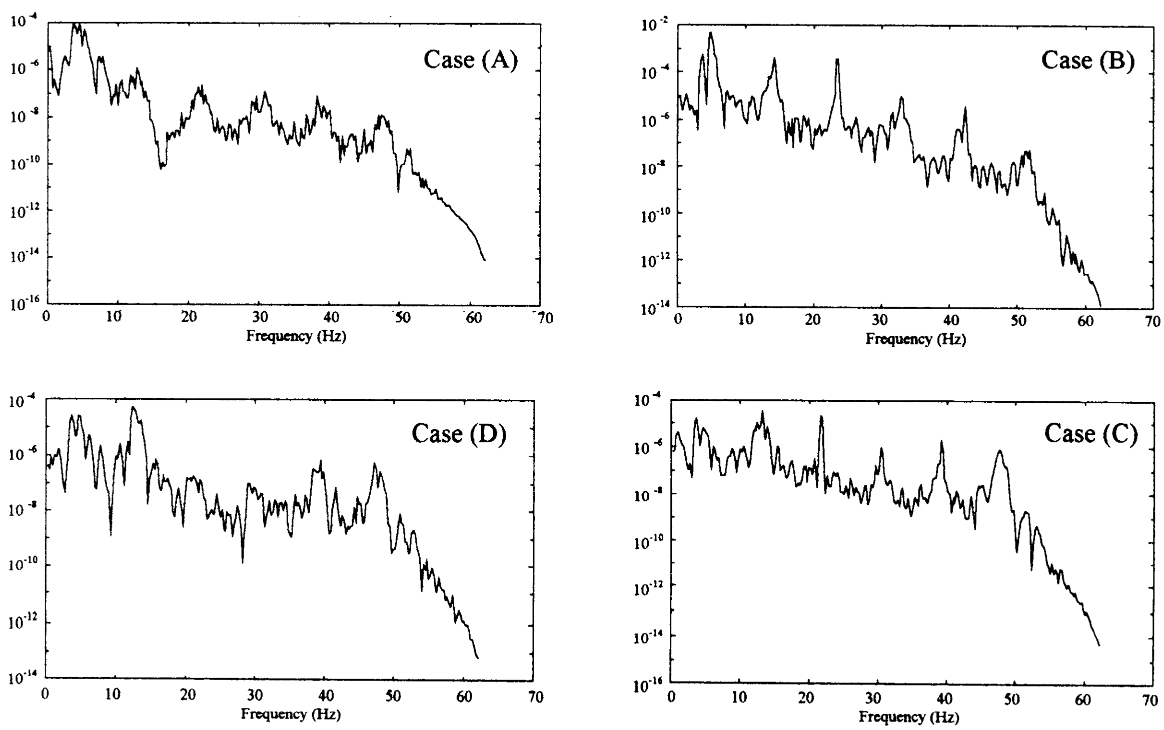

FIGURE 7. PSD of the Second Test Series Processed Results - [V^2/Hz].

CONCLUSIONS

Propellantless propulsion, as a mechanism not requiring reaction mass or beamed power, does not seem to be out of reach, unless from the theoretical point of view. Space-time warping (and the involved enormous energies) is nor necessary, provided inertia manipulation become feasible, within the framework of a mass tensor formalism. This may be the case with the inertia's electromagnetic part if some existence conditions are satisfied, like those verified by the formalism based on the Minkowski's Energy-Momentum tensor for the electromagnetic field. However, the validity of this formalism is presently arguable under the still-standing Abraham-Minkowski controversy, the main argument being the unsymetrical nature of that tensor. The issue is then highly relevant to innovative, low-term achievable propulsion concepts. Therefore, experimental elucidation of the controversy was sought and instrumented around a so called EMMG (Electro-Magnetic Momentum Generator) device.

Tests performed during the period 1993 - 1997, with slightly different instrumentation, produced results, which after processing through spectral analysis, system modeling & identification and optimal filtering techniques, when applicable, consistently pointed to a mechanical vibration induced by mass/inertia tensor warping of the device, or matter-electromagnetic field momentum exchange, as predicted by Minkowski's formalism. Obviously, along the processing and analysis activities, other sources of vibration were taken into account, or removed when possible, according to a systematic error and disturbance (spurious effects) fighting procedure. Nevertheless, no direct detection of the sought effect by means of input reconstruction was obtained up to now and much work remains to be done to assess, beyond all doubt, the validity of these encouraging results. One of the main concern is power supply induced EMI interference due to bad grounding and/or shielding, sharing the same spectral signature with the pursued effect. Had that validity be fully demonstrated, the concept developed in this paper would just be the seed for a restricted class of "propellantless" propulsion: that of "converter" (one shot, or back and forth) type. Present Physics seems to preclude any further progress along this line of work, unless ZPF or some new paradigm come to the rescue.

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NOMENCLATURE

c	= velocity of light in an arbitrary medium, m/s
$\mathbf{f}$	= external 4-force, N
g	= 3-momentum density in an arbitrary frame, kg · m/s
$\mathbf{G}$	= system 4-momentum in an arbitrary frame, kg · m/s
$\mathbf{I}$	= 4-space metric tensor
M	= Minkowski space
$\mathbf{M}$	= 4-space mass tensor, kg
m_{EM}	= mass of the electromagnetic field, kg
m_0	= spaceship rest mass, kg
$\mathbf{p}_{EM}$	= 4-momentum of the electromagnetic field, kg · m/s
s	= energy flow, W/m^2
t	= time, s
$\mathbf{T}$	= energy-momentum tensor, kg · m/s
$\mathbf{u}$	= 4-velocity of "matter" rest frame, m/s
$\mathbf{v}$	= 4-velocity, m/s
V	= 3-D region, volume
w	= energy density, J/m^3
x	= location vector in 3-D space, m
$\mathbf{x}$	= event in spacetime, m
τ	= proper time, s

Subscripts

0	= at rest, in vacuum

Superscripts

f	= field
m	= matter, mechanical
T	= transpose
*	= rocket center of mass rest frame, center of energy density variation rate