

Experimental Study of the Machian Mass Fluctuation Effect Using a μN Thrust Balance

Nembo Buldrini, Klaus Marhold, Bernhard Seifert, Martin Tajmar

*Space Propulsion Section, ARC Seibersdorf research GmbH, 2444 Seibersdorf, AUSTRIA
+43(0)50550-3137, nembo.buldrini@arcs.ac.at*

Abstract. Already since 1990, James F. Woodward, professor of physics at the California State University, provided a set of equations showing that it should be possible, via Mach's Principle, to change transiently the mass of a body. Several devices were developed, that suggest that the phenomenon is real. The main goal of the experimental campaign proposed here is to perform an independent test for the existence of machian mass fluctuations: we will study the behavior of a test device using a very sensitive thrust balance developed for field emission thrusters. The balance has a sub μN accuracy, which should prove the effect at least with a thrust-to-noise ratio of 100:1. This mass fluctuation effect, if proved to be genuine, would open the doors to a new kind of propellantless propulsion which could be directly applied to space exploration. Another aspect of our work is to explore also the possibility to achieve higher power efficiency and a more compact design, making then these devices attractive for practical application.

Keywords: Propellantless Propulsion, Mach's Principle, Thrust Balance, Inertia, Gravity, Ceramics, Woodward Effect.

PACS: 85.50.-n, 83.60.Np, 04.80.Cc

INTRODUCTION

The need of efficient space propulsion systems has stimulated several researchers to investigate new pathways in modern physics, in search of a theory or a phenomenon that could be exploited for this purpose. Nevertheless, even if some intriguing developments exist in this field, there is lack of experimental evidence: either the experiment gives inconclusive results, or the required test is not affordable because of our limited current technological capability. In any case there are no overall accepted experimental proofs that demonstrate such advanced propulsion systems are feasible. In 1990, James F. Woodward started to get interesting results in experiments pursued to demonstrate that the inertia of a body is the result of Mach's Principle, that is, it arises from the gravitational interaction with chiefly distant matter in the universe. Since then, he and other researchers have been obtaining remarkable results that are giving step by step a more complete view of the phenomenon, suggesting that what is detected is a genuine effect. The test outcomes show that a propellantless, high efficiency, high range thrust propulsion seems indeed feasible. Continuing experimental verifications are strongly recommended in order to confirm the genuineness of the effect and to start harnessing his considerable potential.

THEORETICAL CONSIDERATIONS

As is our intention to focus this paper on the experimental facet, we will give here just a short description of the theoretical background, reporting the final equations used to model the propulsive force generated by the devices. Nevertheless we encourage the reader to consider the full theoretical aspects that have already been extensively treated in the papers cited in the references (Woodward, 1990, 1996, 2004a, 2004b, 2005; Mahood, 1999; Mahood, March and Woodward, 2001; March, 2004; March and Palfreyman, 2006; Woodward and Vandeventer, 2006).

Following the formalism adopted in Woodward (2005), proper matter density fluctuation arising from machian "gravinertial" interactions may be written as:

$$\delta\rho_0(t) \approx \frac{1}{4\pi G} \left[\frac{1}{\rho_0 c^2} \frac{\partial^2 E_0}{\partial t^2} - \left(\frac{1}{\rho_0 c^2} \right)^2 \left(\frac{\partial E_0}{\partial t} \right)^2 \right]. \quad (1)$$

Capacitors excited by an alternating voltage are one possible system where large, rapid fluctuations in E_0 can easily be affected that should produce periodic mass fluctuations δm_0 that might be put to use to generate stationary forces. That mass fluctuation is just the integral of $\delta\rho_0(t)$ over the volume of the capacitor, and the corresponding integral of the time derivatives of E_0 , since $\partial E_0/\partial t$ is the power density, will be:

$$\delta m_0 \approx \frac{1}{4\pi G} \left[\frac{1}{\rho_0 c^2} \frac{\partial P}{\partial t} - \left(\frac{1}{\rho_0 c^2} \right)^2 \frac{P^2}{V} \right], \quad (2)$$

where P is the instantaneous power delivered to the capacitor and V its volume. The predicted mass fluctuation can be computed using Equation (2) above which, after differentiation of $P=P_0 \sin(2\omega t)$ and ignoring the second term on the RHS, reads:

$$\delta m_0(t) \approx \frac{\omega P_0}{2\pi G \rho_0 c^2} \cos(2\omega t). \quad (3)$$

A simple way to get unidirectional force is to make the capacitor oscillate at a rate that it is accelerated in one direction when the mass undergoes a positive fluctuation and in the other direction when the fluctuation is negative. Several devices have been built that used piezoelectric materials to exert an oscillating force on a capacitor subject to mass fluctuations (Woodward 1996; Mahood, 1999; Mahood and Woodward, 2000; Mahood, March and Woodward, 2001). A more reliable and convenient method to apply this force is the use of a magnetic field perpendicular to the displacement current in the capacitor (Brito, 2003; Woodward, 2004a, 2004b, 2005; March, 2004; Woodward and Vandeventer, 2006). If the phase between the current in the coil and the voltage applied to the capacitor is 90 degrees, then a Lorentz force will take place that will act on the dielectric with the right timing, giving rise to a unidirectional force. This can be described with the following formalism:

$$F_B = i_d \times B \times L, \quad (4)$$

where i_d is the displacement current in the capacitor, B the magnetic flux and L the distance between the capacitor plates. Considering that i_d and B are orthogonal by construction and have the same frequency, the force may be expressed as follows:

$$F_B \approx B i_d L \cos \varphi. \quad (5)$$

The total force acting on the supports of the device is the sum of the Lorentz force and the counterbalancing lattice forces:

$$F_{tot} = -(F_B + F_{lat}), \quad (6)$$

which, in absence of mass fluctuations in the dielectric, turns out to be zero. But when mass fluctuations are taken into account, the time-average of F_{tot} no longer vanishes in stationary circumstances if the phase relationship between F_B and i_d and δm_0 is such that F_B acts in phase with the mass fluctuation; thus we can write:

$$\langle F_{tot} \rangle \approx -2 \left(\frac{\delta m_0}{m_0} \right) F_B \sin \varphi, \quad (7)$$

where the phase angle φ is that between the voltage applied to the capacitor and the current in the inductor. The factor of 2 arises from the fact that the mass fluctuation peaks with reversed sign when the lattice restoring forces act during each cycle.

Although there are several works confirming experimentally the existence of this mass fluctuation effect, the agreement of the results with the theory is not yet completely fulfilled. Usually the predictions underestimate observations by a factor of 2 to several hundreds, depending on the theoretical model adopted. This mismatching can arise from several factors, as the interactions at atomic level involved in the production of such mass fluctuations could reveal themselves more complex than expected. Moreover, another theoretical approach has been proposed by H. Brito, based on purely electromagnetic considerations (Brito and Elaskar, 2003; 2005). It is interesting to notice that Brito himself has performed experiments with devices of this sort, obtaining interesting results as well.

THE THRUST BALANCE

The balance employed in this work (Marhold and Tajmar, 2005) has been especially developed to measure the thrust produced by In-FEEP (Indium Field Emission Electric Propulsion) thrusters, designed and manufactured at ARC Seibersdorf research. The force produced by single thrusters of this sort falls in the micronewton range, reaching millinewtons for clustered systems.

The balance consists of a symmetric arm (a hollow rectangular aluminum profile with a side length of 20mm and a total length of about 60cm) which is free to rotate by means of two flexural pivots. The pivots have been selected because of their low friction, high linearity and negligible hysteresis. In addition they are able to support large loads (in the order of a few kilograms). The selected flexural pivot is a G-10 pivot from C-Flex Inc. (NY, USA). When the thruster, which is mounted to one end of the arm is switched on it will exert a force on the arm, causing it to shift its position. The deflection of the balance is a linear function of the applied force. Additionally, the measurable thrust range is adjustable, changing either the position of the sensor or of the thruster (the distance of those two to the center of rotation). Moreover the flexural pivot can be substituted by a pivot with a different torsional spring rate.

Different sensors have been evaluated to measure the deflection of the thrust balance. The sensor selected is a D64 fiber optic displacement sensor (Phltech Inc., USA). It works by measuring the reflection of light from the target surface. A big advantage of this sensor is that the part inside the vacuum chamber consists only of optical fibers, thus the signal cannot be influenced by electromagnetic interferences.

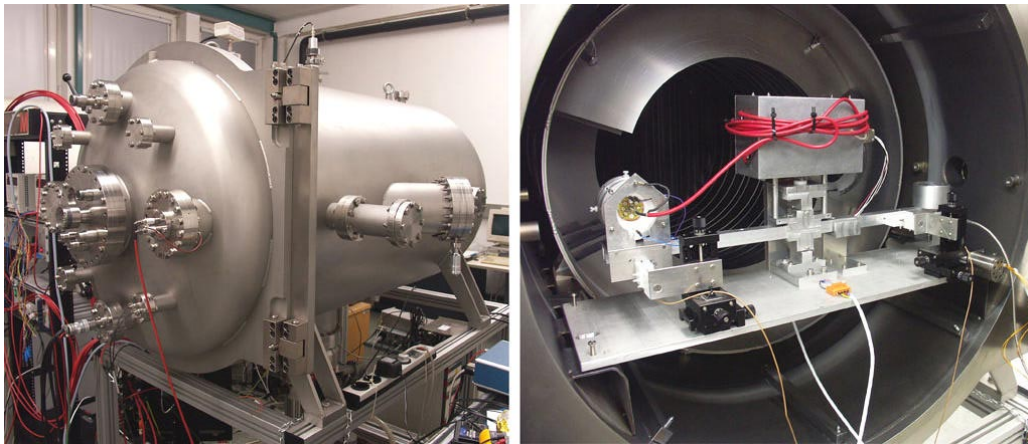


FIGURE 1. The Vacuum Chamber Used for the Test and the Thrust Balance Mounted Inside the Chamber for an In-FEEP Test.

The typical response curve of the sensor allows the operation of the sensor in either the so called ‘near side’ or the ‘far side’. The near side offers a higher sensitivity at the cost of a decreased linear measurement range (this limits the measurable thrust range and makes the initial setup of the balance more complicated). The far side has a worse sensitivity but a much larger measurement range.

In order to simplify the initial setup of the balance and to be able to use both operating modes of the sensor a movable sensor mount has been designed. A vacuum compatible stepper motor driving a high precision stage allows the movement of the sensor head. By following the response curve of the sensor one can set the working point either in the near or far side of the sensor.

Because the flexural pivot used has low friction, the motion of the balance would be almost without dampening. In order to reduce oscillations of the arm a damping system had to be included in the design. Possibilities included oil dampers, electromagnetic dampers and damping by electrostatic forces. The damping system selected for the balance is of the last kind. The signal from the displacement sensor is recorded into the computer, is differentiated, amplified and fed into the voltage command input of a HV power supply which is connected to a special comb assembly. This works as a velocity proportional damping system. The level of damping can be conveniently set in the control software.

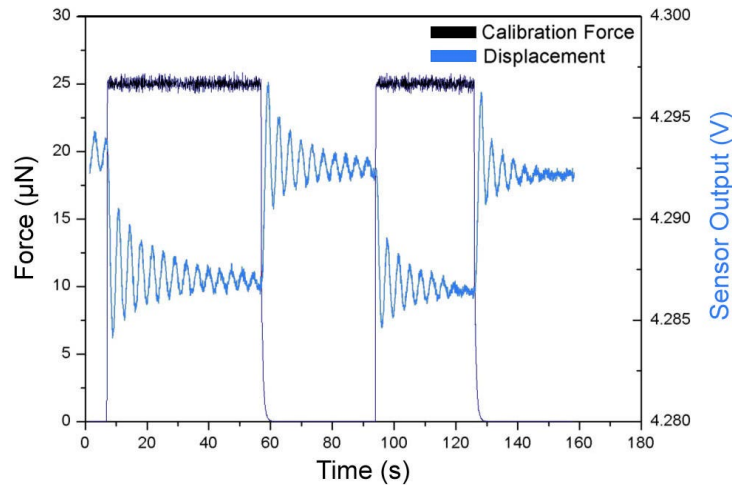


FIGURE 2. Response of the Balance to a Calibration Force.

A typical response of the balance is shown in Fig. 2. As a calibration force of $25\mu\text{N}$ is applied by electrostatic comb actuators, the arm moves to a new position. The oscillations are gradually reduced by the damping system. After switching off the voltage supply for the electrodes the balance returns to its original position. Note that when the calibration force is switched on again the balance is damped stronger because the level of damping has been changed in the control software. This is not the highest possible level; further tests will have to show the optimum damping. In general it is preferred to reach a steady state as quickly as possible to minimize measuring time.

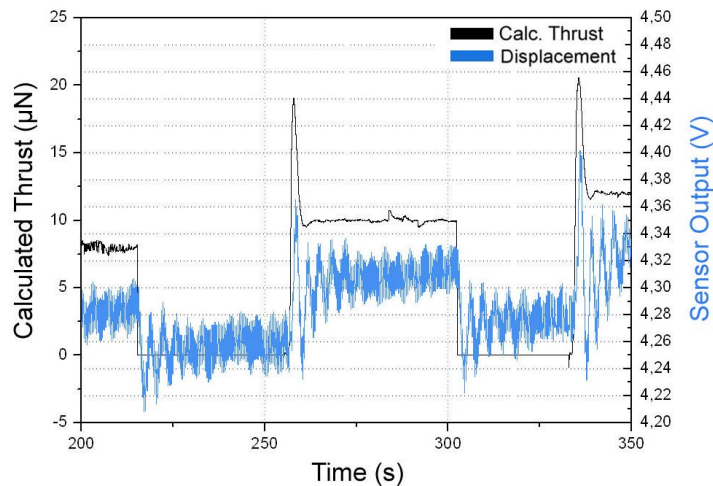


FIGURE 3. Balance Response to In-FEEP Firing.

Figure 3 displays the response of the balance to the force produced by a real In-FEEP thruster. The black trace represents the thrust calculated using the electrical values of the ion thruster: in this case the force was about $10\mu\text{N}$.

In this run the displacement sensor has been used only in the range with less sensitivity to simplify the setup of the balance in the vacuum chamber. As the thrust produced by the Mach5C device is expected to be $50\mu\text{N}$ circa, the same range could be used in our verification tests. If it will turn out to be necessary, however, the position of the sensor head can be automatically adjusted to measure with higher sensitivity.

EXPERIMENTAL ACTIVITY

The first phase of our experimental work will consist in the reproduction of one of the last experiments of Woodward. The device object of the tests, named Mach5C, is an original device from Woodward (Woodward and Vandeventer, 2006). It comprises two 2.2 nF 15 kV Vishay Cera-Mite capacitors (Z5U dielectric, $\epsilon_r \approx 8500$) glued between the halves of a toroidal inductor core and connected in parallel (measured total capacitance: 4.95 nF). The magnetic flux through the capacitors needed to produce thrust is generated by two coils wound over the capacitors. The measured inductance of the two coils connected in series is $680\mu\text{H}$. In previous measurement sessions, Woodward recorded a thrust of about $50\mu\text{N}$. Considering a resolution of $1\mu\text{N}$ typical for our thrust balance, it should not be difficult to point out the sought effect.

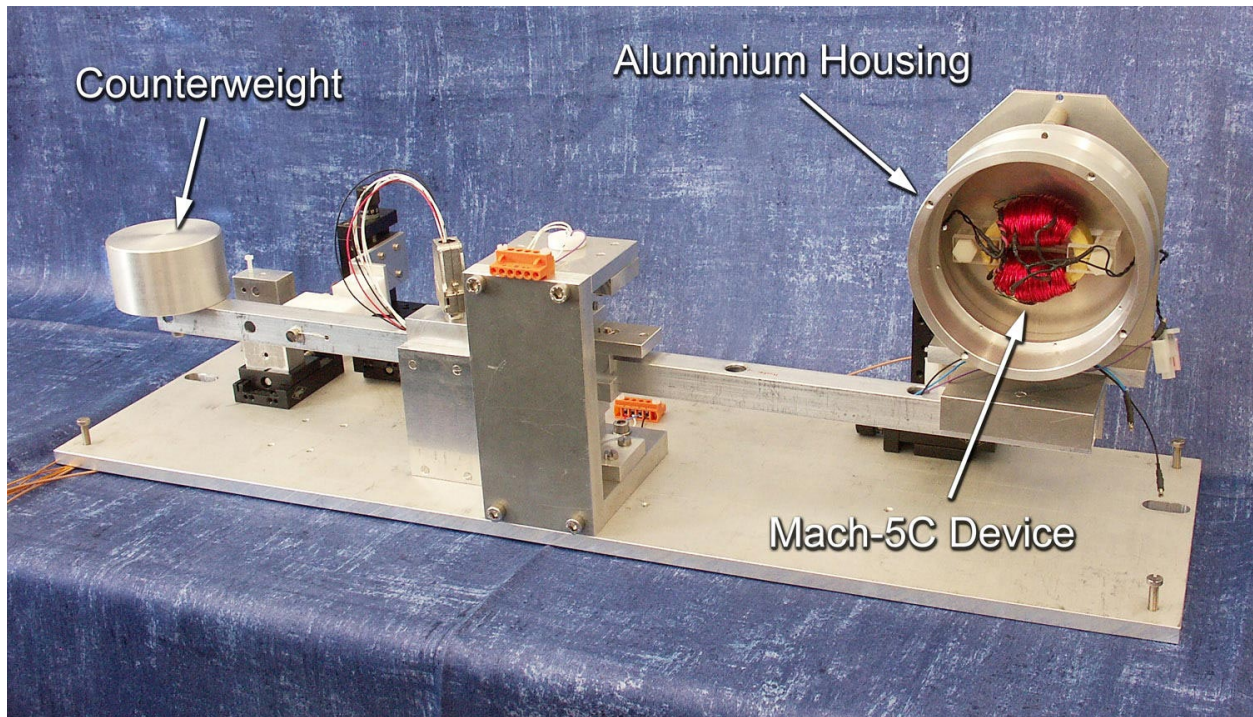


FIGURE 4. The Mach5C Device (on the Right) Mounted on the Balance.

Figure 4 depicts the Mach5C device mounted on the thrust balance. This is a preliminary arrangement where the electrical connections are not yet implemented. On the left it is possible to see the counterweight: the white Teflon blocks next to it constitute part of the damping system actuator. The article is enclosed in an aluminium housing (122mm external diameter, 54mm height) that will provide EM radiation shielding and mechanical coupling with the thrust balance. Between the top cover and the main housing a space of some millimeters is left (see Figure 5), in order to allow a proper outgassing of the device (the tests are performed at a pressure of 10^{-6} mbar). Such an outgassing slit solution was selected also to avoid other problems during the test of the article: since an abrupt outgassing episode of some extent is expected every time the device will be connected to the power supply (as result of the increase of temperature), spurious thrust signals coming from gas emission are probable and have to be avoided. The slit provides a radial outlet, so that even if the outgassing is not uniformly distributed over the rim, the disturbance will be minimized as the thrust vector will be perpendicular to the sensitive thrust axis of the balance.

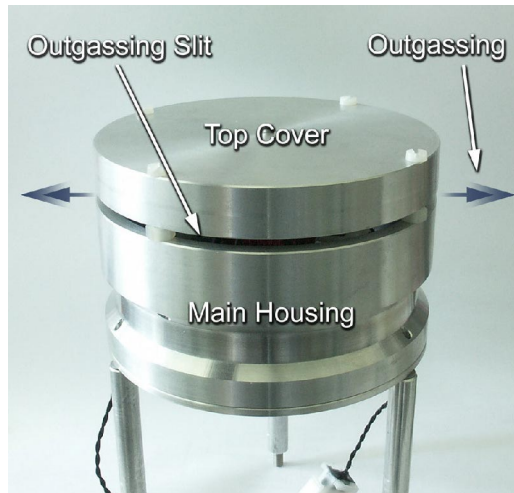


FIGURE 5. The Radial Outgassing Slit.

The device will be driven by two Carvin DCM2500 audio amplifiers (same model used by Woodward and March), in order to provide a faithful replication of the original experiment. One amplifier will drive the coil and the other one the capacitors. Step-up transformers are needed to elevate the voltage level from the output of the amplifiers. The signal generator used to pilot the amplifiers is a 2 channel wave synthesis generator connected via USB to the DA computer. It is able to generate various waveforms with a maximum frequency of 200kHz. The phase shift of each signal can be adjusted via software from 0 to 180 degrees continuously. Having the two signals supplied independently gives the possibility to check the dependence of the thrust produced on the relative phase shift, thus eliminating some possible spurious results. Much attention has to be paid in feeding the audio frequency power to the device: as the cables have to be robust enough to carry high power levels, a mechanical interference with the balance cannot be excluded.

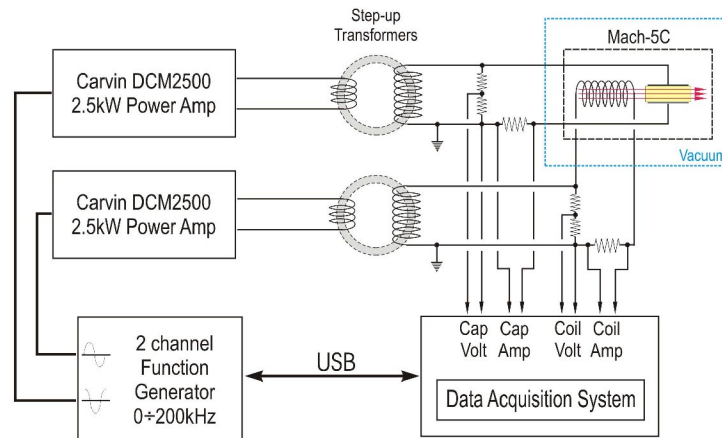


FIGURE 6. The Experimental Setup with Independent Capacitor/Coil Driving.

Dedicated Labview software will be used to manage the operation of the device and the acquisition of the data. For each shot, the start and the duration of both signals can be set independently. An overheating problem has been displayed by Woodward and March that causes a sensitive reduction of the thrust produced with the increase of the temperature in the dielectric of the capacitors: each shot was therefore kept as short as possible. Nevertheless, because of the balance natural oscillation period, a longer single shot could be needed. This can be accomplished supplying the device with lower power levels, with the purpose to allow a slower temperature increase: the high sensitiveness of the balance will compensate for the lower thrust produced.

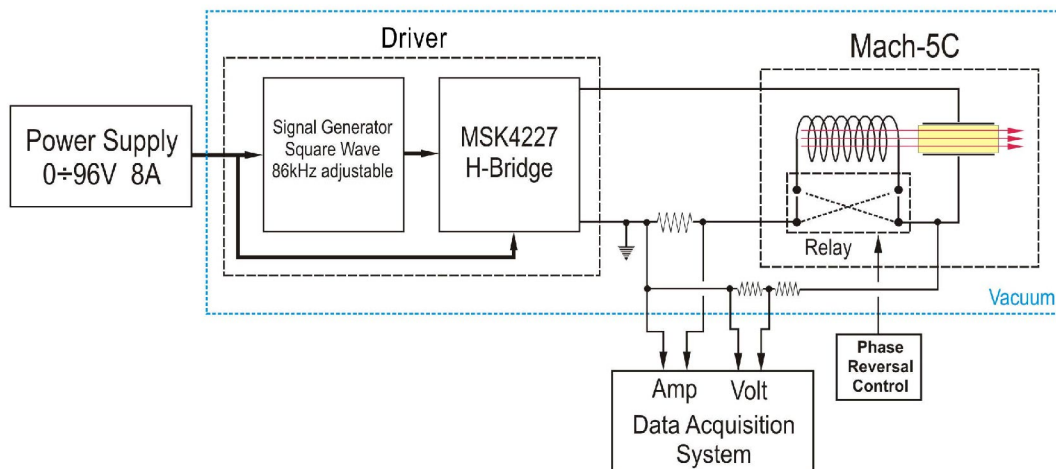


FIGURE 7. Schematics of the Arrangement for Resonance Operation.

In the second experimental phase (Figure 7) a mini Class-D amplifier will be employed to drive the device in resonant mode with the coil and the capacitor connected in series. Driving the coil and the capacitor in a series (or parallel) configuration has two desirable advantages: 1) the voltage on the capacitor and the current in the coil have always a relative phase shift of 90 degrees, thus, via Equation (7), maximum thrust is obtainable; 2) at resonance, high voltage (or current) values are built up inside the device leading to high reactive (not dissipative) power levels on the order of several kVA with a relatively low driving power, related only to the dissipation factor of the circuit. This last advantage allows moreover the use of smaller cables for the power supply, reducing the interference with the balance; even the use of a battery could be considered, hence eliminating the need of power supply cables passing through the balance. Two specially wired relays will be employed in the inductor line to shift the phase of the coil by 180 degrees: this expedient provides the option to reverse the thrust produced. The driver used in this configuration has been expressly developed to work in vacuum and it will be mounted directly on the balance, close to the Mach5C device. It consists of one MSK4227 H-Bridge capable of generating a square wave of max 200V (20A max current). Using the square wave allows the shortest switching time possible, reducing at a minimum the switching losses. Applied to the resonant LC tank circuit, the square wave is “filtered” and only a pure sine wave will be present in the circuit, eliminating the other harmonics, unwanted for a proper device operation.

FURTHER DEVELOPMENTS

Other mass fluctuation devices are being developed here at ARC-sr in order to explore the force production at higher frequencies and using different dielectric materials. One device consists of high power ceramic capacitors, designed for high frequency duty (dielectric: N750, $\epsilon_r \approx 120$) and a series coil, driven at resonance in the MHz range. Although the dielectric relative permittivity is quite low compared to the one of the material employed in the capacitors of the Mach5C, the dissipation factor is one order of magnitude lower, thus allowing the use at higher frequency without incurring in overheating. With a device of this sort, longer shot duration will be furthermore possible, enabling the study of steady thrust production.

CONCLUSION

The intent of the work presented in this paper is to demonstrate once again that the thrust produced by devices like Mach5C is a repeatable and controllable event. The chance to have a thruster with infinite specific impulse, together with the possibility to obtain pretty high efficiencies operating at resonance with low dissipation factor (high Q) circuits, should be sufficient arguments to promote further studies and developments on this topic. If the mass fluctuation effect continues to be confirmed by rigorous and clear experiments, a precursor spaceborne experiment should be considered as the next natural step.

NOMENCLATURE

B, B	= magnetic induction (T)
c	= vacuum speed of light (m/s)
δm_0	= mass fluctuation amplitude (kg)
E_0	= proper energy density (J/m ³)
ϵ_r	= relative permittivity
φ	= relative phase (degrees)
F_{tot}	= total force (N)
F_B, F_B	= magnetic part of the Lorentz force (N)
F_{lat}	= lattice restoring forces (N)
$\langle F \rangle$	= time-averaged force (N)
G	= Newtonian constant of universal gravitation (Nm ² /kg ²)
i_d, i_d	= Electric displacement current (A)
L	= length of the displacement current path (m)
m_0	= proper mass (kg)
P	= instantaneous power (W)
ρ_0	= proper density (kg/m ³)
V	= capacitor dielectric volume (m ³)
ω	= angular frequency (rad/s)

ACKNOWLEDGMENTS

The main thankfulness goes to Dr. Jim Woodward: without his material contribute and the continuing inspiration of his work during the last ten years, this paper wouldn't have been a reality. Many thanks go out to Paul March, Andrew Palfreyman, Peter Vandeventer, Tom Mahood and other colleagues for providing useful discussions.

REFERENCES

- Brito, H. H. and Elaskar, S. A., "Direct Experimental Evidence of Electromagnetic Inertia Manipulation," in *39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, AIAA 2003-4989, Huntsville, Alabama, July 2003.
- Brito, H. H. and Elaskar, S. A., "Overview of Theories and Experiments on Electromagnetic Inertia Manipulation Propulsion," in proceedings of *Space Technology and Applications International Forum (STAIF-2005)*, edited by M.S. El-Genk, American Institute of Physics Conference Proceedings 746, Melville, NY, 2005, pp. 1395-1402.
- Mahood, T. L., "A Torsion Pendulum Investigation of Transient Machian Effects," California State University – Fullerton (CSUF), Masters Thesis, 1999.
- Mahood, T. L., March, P., & Woodward, J. F., "Rapid Spacetime Transport and Machian Mass Fluctuations: Theory and Experiments," *37th AIAA/ASME/SAE Joint Propulsion Conference*, AIAA 2001-3907, July 09, 2001.
- Marhold, K. & Tajmar, M., AIAA 2005-4387, "Micronewton Thrust Balance for Indium FEEP Thrusters," *41st AIAA/ASME/SAE Joint Propulsion Conference*, Tucson, Arizona, July 2005.
- March, P., "Woodward Effect Experimental Verifications," in *Space Technology and Applications International Forum (STAIF-2004)*, edited by M.S. El-Genk, AIP Conference Proceedings 699, Melville, NY, 2004, pp. 1138-1145.
- March, P. & Palfreyman, A., "The Woodward Effect: Math Modeling and Continued Experimental Verifications at 2 to 4 MHz", in these proceedings of *Space Technology and Applications International Forum (STAIF-2006)*, edited by M.S. El-Genk, American Institute of Physics, Melville, NY, 2006.
- Woodward, J. F., "A New Experimental Approach to Mach's Principle and Relativistic Gravitation," *Foundation of Physics Letters*, **vol. 3**, No. 5, 497-506 (1990).
- Woodward, J. F., "A Laboratory Test of Mach's Principle and Strong-Field Relativistic Gravity," *Foundations of Physics Letters*, **vol. 9**, No. 3, 247-293 (1996).
- Woodward, J. F., "Flux Capacitors and the Origin of Inertia," *Foundations of Physics*, **vol. 34**, 1475-1514 (2004a).
- Woodward, J. F., "Life Imitating "Art": Flux Capacitors And Our Future in Spacetime," in proceedings of *Space Technology and Applications International Forum (STAIF-2004)*, edited by M.S. El-Genk, AIP Conference Proceedings 699, Melville, NY, 2004b, pp. 1127-1137.
- Woodward, J. F., "Tweaking Flux Capacitors," in proceedings of *Space Technology and Applications International Forum (STAIF-2005)*, edited by M.S. El-Genk, AIP Conference Proceedings 746, Melville, NY, 2005, pp. 1345-1352.
- Woodward, J. F. & Vandeventer, P., "Mach's Principle, Flux Capacitors, and Propulsion," in these proceedings of *Space Technology and Applications International Forum (STAIF-2006)*, edited by M.S. El-Genk, AIP, Melville, NY, 2006.

Copyright of AIP Conference Proceedings is the property of American Institute of Physics and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.