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Propellantless Propulsion: Recent Experimental Results Exploiting Transient Mass Modification

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Abstract. An assortment of papers have been published over the years setting forth theory suggesting inertia stems from the gravitational effects of the totality of matter in the universe (Mach's Principle). This has been supported by positive results of experimental attempts by Woodward to transiently modify the inertia of test masses. By rapidly oscillating the energy density of the test masses (i.e., charging and discharging high-energy capacitors), apparent transient mass shifts of up to ± 10% of the active dielectric material were consistently obtained. It became apparent that such an effect, when coupled with precisely timed external impulsive forces, could result in a net force, that is, propulsion without the expulsion of a reactive propellant, utilizing only electricity as "fuel". Several generations of devices have been constructed and tested supporting this concept of propulsion.

INTRODUCTION

Over the past 8 years several papers have been published putting forth the rather startling theory that the mass of a capacitor dielectric may be transiently modified by simply subjecting the capacitor to rapid charge/discharge cycling, at high power levels, Woodward (1991), (1992) and (1996). Indeed, if this theory is correct, transient mass shifts are occurring in a multitude of electronic equipment in use today. However because the effect is normally small and very transient, time averaging to zero after each cycle, it's not surprising the effect has been overlooked. It's also not too surprising the research has generally received little notice, due to the "science fiction" nature of the concept. It does, after all, "seem too good to be true."

But is it too good to be true? Examination of the theory and its derivation show it to be fairly sound, arising in a straightforward manner out of Special Relativity Theory, as an embodiment of Mach's Principle. (Mach's Principle being the contention that the inertia of an object is a result of that object's gravitational interaction with the rest of the matter in the universe.) But equally important to its apparent theoretical soundness is the considerable body of experimental data supporting the predictions of this theory. Lack of space precludes this paper from presenting the detailed derivation of the effect, so readers are encouraged to review Woodward (1992) and (1996) for the complete theoretical derivation and earlier experimental results. However a brief overview of the salient points is in order.

THRUST GENERATION VIA TRANSIENT MASS SHIFTS

If one is in possession of an object (a capacitor in this case) whose mass is rapidly oscillating between larger and smaller values, how might one best utilize it to produce a thrust or unidirectional force (UDF)? It turns out this may be readily accomplished by giving the capacitor a "push" when it's in its heavier phase, and a "pull" when it's lighter (or vice versa). To do the pushing and pulling, a piezoelectric transducer (PZT), phase-locked to the mass shift frequency of the capacitor, is an obvious choice. The basic concept is to securely couple the capacitor (or multiple capacitors) in some manner to a PZT unit and use the PZT to "vibrate" the capacitor at an optimum phase offset. It turns out that making the driving signals of both the capacitor and PZT sinusoidal has a rather beneficial effect. The multiplication of two sinusoids of the same frequency, but differing in phase, results in a constant, static offset. In this case the offset is the thrust or UDF.

Combining the conclusions of Woodward (1992 and 1996), the time averaged, static force in newtons, <F>, is predicted to be:

$$< \mathrm{F} >= \mathrm{f}^3 dl_{PZT} \mathrm{P}_{Cap} (2.6 \times 10^{-13}) \,, \tag{1}$$

Where f = Frequency of the capacitor charging signal in Hz.
dl_{PZT} = Amplitude of the PZT excursion in meters.
P_{Cap} =Amplitude of the power delivered to the capacitor in watts.

Note that since one capacitor cycle has two periods of charge and discharge, the PZT operates at twice the capacitor's frequency.

Since the force produced goes up with the cube of the frequency, at first glance this simple equation suggests enormous forces might be generated utilizing very high frequencies and/or high power levels. Alas, it is not quite that simple. This equation is actually a linear approximation of a more complex expression. At high powers or frequencies, non-linear effects come into play, altering the force predicted by this simple equation. Still, at moderate frequencies and powers, forces in the tens or hundreds of newtons may be eventually attainable.

Any reasonable person considering such a fantastical scheme should immediately object that it clearly violates conservation of momentum laws, and therefore can't possibly work. At first glance, such concerns are perfectly understandable, so this issue deserves at least a brief elaboration. Since the derivation of the transient mass effect comes from a straightforward relativistic generalization of Newton's second law, one can justifiably demand all momentum within an isolated system must balance. The trick here is determining what constitutes the isolated system these devices operate in. Since the inertial force presumably arises from all other matter in the universe (a very "non-local" interaction), manipulations of this inertial force must induce reactions in its source, the rest of the universal matter. The boundaries of the system under consideration must be drawn to include all interacting components. Since these effects appear instantaneous, it presupposes the momentum transfer is accomplished via advanced and retarded disturbances propagating at a speed of c between the devices and all matter in the universe. Given this scenario, conservation of momentum is not violated, despite superficial appearances.

FIRST GENERATION DEVICE

The first clearly successful device consisted of a ring of six 0.01 uF, 3kV capacitors mounted on a PZT stack. Each capacitor was about 0.8cm square and 0.2 cm thick and fabricated of a specialized material to reduce electromechanical effects. The PZT stack was formed of 40 individual PZT discs bonded together to create a cylindrical transducer 1.9 cm in diameter and 2.5 cm tall. The PZT stack was placed between the capacitors and a massive plate, and the capacitor ring clamped to the plate, squeezing hard against the PZT stack. The entire unit was then placed within a RF and magnetically shielded test cell containing an exquisitely sensitive Hall effect weighing device with extremely fast response times. This weighing device used the Hall effect transducer to measure the deflection of a steel diaphragm. Data was recorded and the system controlled via a PC. The entire experimental setup and protocols are described in great detail in Woodward (1996).

This device, operating at a frequency of 11 kHz, a capacitor power level of 145 watts and a PZT excursion of less than 10^{-9} meters, consistently produced forces on the order of $5\text{x}10^{-5}$ newtons. These forces were small enough that many measurements had to be taken and averaged, to eliminate the noise masking the actual force signal, but the signal was clearly above the noise value of the weighing device. These values were at least several orders of magnitude less than predicted, given the known or estimated parameters.

It was suspected the low force output might be due to the method by which the capacitors were clamped to the PZT. The necessarily firm clamping tended to strongly suppress the motion of the PZT, which in turn meant the capacitors were subjected to much less of an excursion. Plans were drawn for a new device to overcome this restricted excursion.

SECOND GENERATION DEVICE

To properly transmit the PZT excursions to the capacitors, the two components have to be firmly in contact at all times. This wasn't a difficulty when the PZT pushed against the capacitors, but it was problem when it became necessary for the PZT to pull the capacitors. PZTs don't lend themselves to tension as well as they do to compression.

To take advantage of the compressive abilities of PZTs, a new configuration was developed, a cross section of which is shown in Figure 1. In this arrangement, an aluminum capacitor holder containing only two (instead of six) of the previously used capacitors was sandwiched between two small PZT stacks, and the entire unit clamped together with aluminum endcaps. The PZTs were hooked up in reverse polarity, so that one stack expanded as the other contracted. The capacitor holder, in the middle of the two PZTs, thus was cleanly and efficiently shuttled back and forth. Since the length increase of one PZT roughly equaled the length decrease of the other PZT, the overall length of the unit stayed essentially the same, and the tension on the endcaps remained constant.

First tests of the new configuration immediately produced outputs in the 2×10^{-4} newton range, a four-fold increase over the first generation unit, while using only a third of the capacitors. Further testing revealed the highest outputs, at levels exceeding 10^{-3} newtons, occurred at a capacitor cycling frequency of around 14 kHz (a 28 kHz PZT frequency). But these higher outputs proved frustrating, as they were difficult to reliably replicate. They were drastically affected by minor changes in frequency and mechanical assembly of the device. Further, several different versions of the configuration were constructed, and each seemed to have its own unique personality, all of which could only be described as "cranky".

The development and addition of tiny accelerometers to the devices finally resolved this peculiar behavior. These little units, only about 0.3 cm square, are fabricated from essentially scrap PZT material less than 0.1 cm thick. Two of these PZT chips are assembled with epoxy into a "sandwich", with a thin brass electrode in-between. On the top is placed a slighter thicker, grounded piece of brass that serves as both a driving mass and an electrode. This driving mass provides force on the PZT chips as it is accelerated during operation. .The unit is then attached to a surface under study with cyanoacrylate adhesive. Each accelerometer is covered with a thin, grounded brass shield to prevent RF pickup, and the output run via thin shielded cables to oscilloscopes for monitoring. These simple devices work exceedingly well, producing signals with peak amplitudes in the 1 volt range when running at 28 kHz.

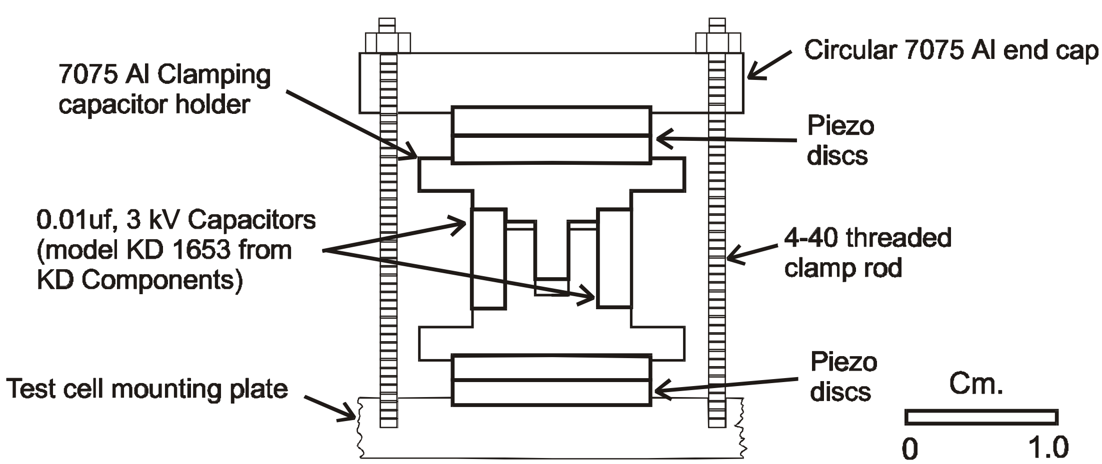

FIGURE 1. A scale, cross sectional view of a second generation device. The capacitors are held in an aluminum capacitor holder, which is in turn sandwiched between two PZT stacks.

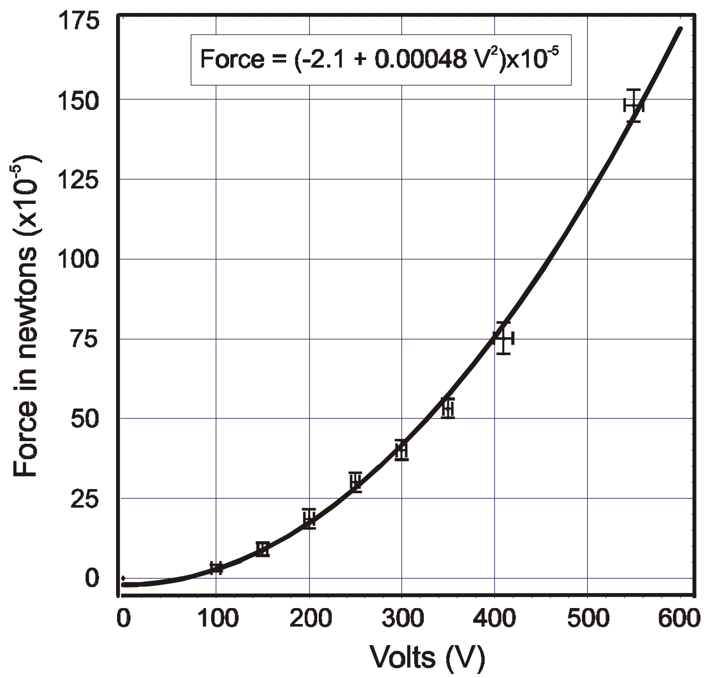

FIGURE 2. A plot of the force output versus capacitor voltage amplitude for a second generation device. The equation is that of the best fit curve within the error bars.

After affixing accelerometers to the end caps and capacitor holder, the device's quirky operation became apparent. In order to get the desired force, the capacitors had to be accelerated, as Mach would have put it, in relation to the fixed stars. But because there were several vibratory modes occurring at the same time, this wasn't always happening. It was also found that minor tensioning changes in the threaded rods clamping the unit together produced radical shifts in the resonant phase relationship between the PZTs and the capacitor holder. Finally, the 28 kHz operating frequency was found to be a resonant frequency of the entire weighing mechanism. This had the affect of providing an additional "boost" of acceleration to the capacitors beyond that provided by the PZTs. It appears the contribution of this resonant acceleration may have value equal to that of the PZT-provided acceleration.

While absolute calibration of the accelerometers was found to be problematic, they did allow for peak turning to maximize the effect. With their addition, the second generation devices became fairly reliable and replicable. Eventually, outputs up to 1.5×10^{-3} newtons were obtained. One such plot of output force versus voltage applied to the capacitors is shown in Figure 2.

THIRD GENERATION DEVICE

A third generation device currently under development builds upon lessons learned from the earlier devices. This latest device is in the shape of a tapered aluminum cone about 10 cm in overall length, and is shown in Figure 3. At the larger diameter end is a short stack of PZTs, and at the tapered tip end are clamped two capacitors. The PZTs are designed to drive the device at a resonant frequency in the 50 to 60 kHz range, which should result in the oscillation of the capacitors at that frequency. The conical tapering should amplify the excursions the capacitors are subjected to, in the manner of an ultrasonic transducer, essentially doubling them. The device is supported at a vibrational node by two slender, flexible rods, which connect down to the usual weighing device's attach point in the test cell. The intent of this connection is to decouple the vibration of the third generation device from the weighing device in the test cell, thus allowing operation at a much higher resonant frequency (50 to 60 kHz) than that of the

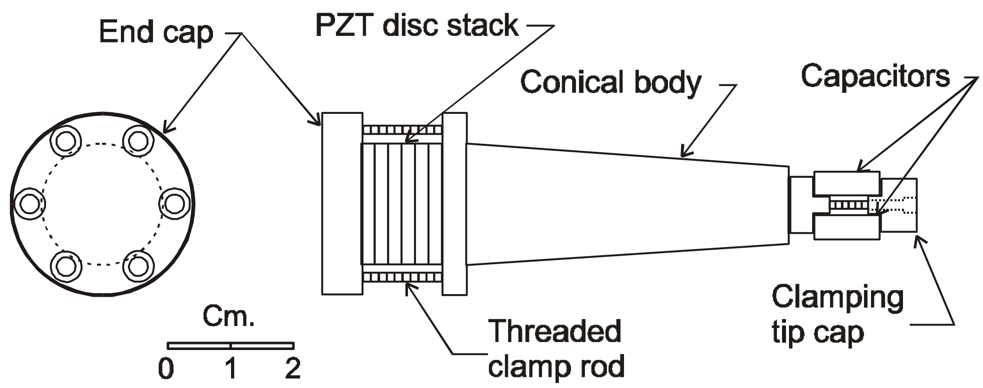

FIGURE 3. A third generation device currently under test. The configuration is modeled after that of an ultrasonic transducer in an attempt to maximize the driven excursion of the capacitors at its tip.

basic resonant frequency of the weighing device (28 kHz). Accelerometers placed on the endcaps of the device allow for tuning to resonant conditions. Very preliminary results indicate force outputs several times those of the second generation units will be obtained, at reduced power levels.

VALIDATION OF EXPERIMENTAL RESULTS

Naturally when faced with effects as sensational as these, one must be extremely cautious not to jump to conclusions, tempting though it may be. Accordingly, a great deal of effort has been spent trying to make this effect "go away." It doesn't, at least when it's not supposed to. While a complete discussion of validation efforts would fill a paper many times the length of this, the topic deserves at least some mention. Some of the validations include:

- Running the devices with the capacitors shorted. In this case, the currents flowing within the device are the same, the mechanical operation is the same, but there is no capacitance and no effect is present.

- To rule out non-linear responses of the weighing diaphragm (of which some are generated during testing), runs were made energizing only the PZT or only the capacitors (the capacitors introduce negligible vibration into the system). Thus the mechanical vibratory modes were duplicated (when running only the PZTs), but unless <u>both</u> PZTs and capacitors were properly energized, the effect was absent. Also, holding the mechanical vibratory modes constant, the effect was noted to scale proportionally to the power applied to the capacitor, while non-linearities should scale with the level of vibratory activity. Finally, it was found operation in a vacuum greatly reduced the oscillatory response, while the stationary effect either remained constant or increased. Were the effect generated by non-linearity of the spring diaphragm, it would scale with the oscillatory amplitude of the diaphragm.

- Duplicating the EM environment within the test cell by running a device with unconnected capacitors, and energizing capacitors immediately adjacent, but unconnected to the device, without effect.

- Running the device in both horizontal and vertical modes to rule out coupling with the local gravitational field. The thrust produced was the same in both orientations.

- Observing the presence of the effect using several "garden variety" capacitors. While thrust produced was very low and partially masked by the noise induced by the electromechanical activity of the capacitors, it was still clearly identifiable.

- Verifying that the output scales proportionally to the power applied to the capacitors, as predicted.

- Noting that peak force outputs correspond with the measured peak, absolute accelerations of the capacitors.

- Shifting the phase relationship between the capacitors and PZTs over a sequence of runs. The results show a shift from a maximum positive force, to a maximum negative force, and back to positive, over 2p radians, as predicted.

- Running the device in a vacuum to rule out spurious effects from ultrasonic standing waves.

- "Inadvertent" validations wherein a capacitor unexpectedly cracks or becomes damaged during a testing sequence and noting the simultaneous drop in the magnitude of the effect.

EXPERIMENTAL PITFALLS

On the face of it, this appears to be a trivial experiment to replicate. Apparently, one should only have to attach a suitable capacitor to a PZT, energize it with appropriate waveforms, and watch it float gracefully above the tabletop. Bitter experience says this is most definitely not the case! The devil is in the details, and there are a great host of traps lurking for the unwary (and even wary) experimenter. What follows is a very shortened list of some of the lessons learned:

- Early device versions used epoxy as a bonding agent between surfaces. This caused no end of problems, as the epoxy had an unpleasant tendency to de-bond due to heat or vibration, in the most inaccessible locations, rendering the entire device useless. Recent versions rely heavily on mechanical connections, which must be of close tolerance due to the small motions involved. The mechanical interfacing between the PZTs and capacitors is absolutely critical, and cannot be overstated.

- Capacitors must be carefully selected with very low electromechanical responses, but at the same time must possess a high energy density. Typical over-the-counter capacitors are not adequate due to the considerable vibration they impart to the system during their operation.

- Acoustical resonances, mismatches and reflections can (and will!) create all sorts of very nasty, spurious signals, often masking real effects.

- Rapidly vibrating objects can set up standing acoustical waves in air, which masquerade as a force. Testing in a vacuum will eliminate these false positives.

- At high power levels, heat buildup must be monitored carefully. PZT material (in the actuators and accelerometers) will de-pole if heated to its Curie point.

- Non-linearities in the weighing system must be identified and carefully accounted for.

EXTRAPOLATION OF THE TECHNOLOGY

Obviously, this work needs to be widely replicated and extensively investigated before serious implementation of the technology can take place. Still, it is easy to see the directions it could lead. The following are a few fairly speculative examples:

- The ability to provide thrust using only electricity as "fuel". Even very modest implementations would allow for indefinite satellite stationkeeping.

- A mechanism to precisely modulate thrust levels, from very low to very high.

- Operation in virtually any environment: Space, atmosphere or water. The only consideration is dissipation of excess heat arising during operation.

- The lack of expulsive material during operation allows for new flexibility for craft design, with the drive unit located internally, or in a sealed situation.

- When coupled to a long-term power source, such as nuclear-electric, relativistic interstellar probes become possible.

SUMMARY

Solid experimental evidence has been quietly accumulating for some time showing transient mass shifts are a real occurrence, a prediction arising in a straightforward manner out of Special Relativity Theory. If this indeed proves to be the case, these transient mass shifts may be exploited to produce a form of "propellantless propulsion", requiring only a source of electricity for operation. Such a radical, new mode of propulsion would have a tremendous impact upon space operations, as well as vast terrestrial uses.

Can this possibly be real? Is it too good to be true? Anyone with reasonable instincts <u>should</u> be skeptical of it. But to dismiss it out of hand, without a thoughtful examination of its physical derivation or a careful experimental replication could prove amusingly shortsighted.

ACKNOWLEDGEMENTS

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