Coulomb repulsion and the electron beam directed energy weapon

Michael Retsky*, Electron Optics Development Co., LLC
237 Strobel Road, Trumbull, CT 06611

ABSTRACT

Mutual repulsion of discrete charged particles or Coulomb repulsion is widely considered to be an ultimate hard limit in charged particle optics. It prevents the ability to finely focus high current beams into small spots at large distances from defining apertures. A classic example is the 1970s era "Star Wars" study of an electron beam directed energy weapon as an orbiting antiballistic missile device. After much analysis, it was considered physically impossible to focus a 1000-amp 1-GeV beam into a 1-cm diameter spot 1000-km from the beam generator. The main reason was that a 1-cm diameter beam would spread to 5-m diameter at 1000-km due to Coulomb repulsion. Since this could not be overcome, the idea was abandoned. But is this true? What if the rays were reversed? That is, start with a 5-m beam converging slightly with the same nonuniform angular and energy distribution as the electrons from the original problem were spreading at 1000-km distance. Could Coulomb repulsion be overcome? Looking at the terms in computational studies, some are reversible while others are not. Based on estimates, the nonreversible terms should be small – of the order of 0.1 mm. If this is true, it is possible to design a practical electron beam directed energy weapon not limited by Coulomb repulsion.

Keywords: Coulomb repulsion, electron beam, directed energy weapon, ballistic missile defense

1. INTRODUCTION – THE ORBITING ELECTRON BEAM DIRECTED ENERGY WEAPON

Over the past few decades, there has been ongoing interest in the concept of using particle accelerators in space as weapons to destroy ballistic missile targets above the atmosphere. While much of this has been kept confidential, Parmentola and Tsipis presented a landmark paper on this subject in Scientific American in 1979[1]. They were participants in the research and, while the review is very critical, there does not seem to be any particular bias so their paper must be considered credible. They presented scientific reasons why such weapons would be highly useful but also dramatized the fundamental reasons why these weapons could never work. Thus this paper is a valuable reference. Any proposed idea must address the fundamental physical limitations pointed out by Parmentola and Tsipis.

Particle beam weapons differ from other instruments of war that carry destructive energy to the target in the form of explosive warheads in ponderous containers such as artillery shells or missile casings. Particle beam weapons, of which electron beams are just one possibility, increase the kinetic energy of a large number of individual atomic or subatomic particles and then direct them collectively against a target. Every particle in the beam that strikes the target will transfer a fraction of its kinetic energy to the target material. If enough particles hit the target in a short time, the deposited energy would be sufficient to burn a hole in the skin of the device, detonate the chemical explosives or disrupt the electronics inside. The most significant advantage of high-energy particle beam weapons over missiles is that, like lasers, they propagate at essentially the speed of light.

My interest in this problem stems from my recently published and patented technological innovation that solves a 100 year-old problem in electron beam deflection.[2,3]. With this technology, a charged particle beam of wide dimensions can be deflected into large angles using electrostatic deflection with little or no deflection aberrations. The invention is surprisingly simple. Merely offsetting the beam toward the attracting plate by a predetermined amount (approximately 1/3 of the gap) will allow a deflected (up to 45 degrees or so) beam to be focussed as well as an undeflected beam. I am currently looking for applications for this technology and, as part of my canvassing, came upon the particle beam weapon problem.

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* michael.retsky@elopt.com   phone: 203-675-0017

While Parmentola and Tsipis also discussed land and sea based defensive applications and included the use of neutral and positively charged beams, I will focus on space based directed electron beam weapons that are intended to destroy distant targets in space. Parmentola and Tsipis presented many small but real practical problems such as how to generate sufficient power in space, how to deal with countermeasures, and how to find targets among decoys. However they discussed two problems that they considered unsolvable. That is, the smaller problems may be considered very difficult scientific and engineering problems that may challenge practical implementation. However, even if all those could be dealt with, two problems remain that are unsolvable due to fundamental physical limitations that no amount of Herculean engineering could resolve.

2. TWO SUPPOSEDLY UNSOLVABLE PROBLEMS

These fundamental problems are first, Coulomb repulsion of the beam spreads the energy over a large area at reasonable distances to targets and second, supposing the Coulomb repulsion problem can be solved, how do you hit a distant rapidly moving target with a charged particle beam considering the somewhat variable near-earth magnetic field. (The beam is assumed to be steered electrically by magnetic fields or electric fields. Mechanical steering would not be fast enough.)

A practical electron beam weapon would need to hit a target 1,000 km away with a 1000 amp beam with an energy of 1 GeV for 0.1 msec. Furthermore the beam needs to be 1 cm or so in diameter at the target. They indicate without references that a 1 GeV electron beam of 1000 amps would spread from an initial 1 cm diameter to 5 meter diameter at 1,000 km due to Coulomb repulsion. They also indicate that a 1 Gev beam would be deflected by 1,000 km over a distance of 1,000 km due to the earth's magnetic field – that is not completely steady. Accepting their reasonable arguments, under these conditions it seems impossible to make a workable weapon that could reliably hit a target 1000 km away with enough energy to destroy it. Also there are only 400 or so seconds to distinguish between multiple targets and decoys in the initial phase of a ballistic missile's trajectory and then destroy the targets. There is more time near the apogee section of travel.

Assuming the first problem is solvable, what about the second problem? Parmentola and Tsipis asked how this device could be used to hit a target 1000 km away while the beam is deflected by terrestrial fields 1000 km off a line of sight to the target. These two problems are shown schematically in fig. 1

Fortunately, there has been much learned about near-earth magnetic fields in recent years[4]. The near-earth magnetic field is 97% due to the core and ranges in magnitude from 30,000 nanoTesla (nT) at the equator to 50,000 nT at the poles. The solar quiet magnetic field variation is a manifestation of an ionospheric current system. Heating at the day side and cooling at the night side of the atmosphere generates tidal winds which drive ionospheric plasma against the geomagnetic field inducing electric fields and currents in the dynamo region between 80-200 km in height. The current system remains relatively fixed to the Earth-sun line and produces regular daily variations that are directly seen in the magnetograms of geomagnetic "quiet" days. On "disturbed" days there is an additional variation that includes superimposed magnetic storms. Because the geomagnetic field is strictly horizontal at the magnetic equator, there is an enhancement of the effective Hall conductivity, called the Cowling conductivity, which results in an enhanced eastward current, called the equatorial electrojet, flowing along the day side magnetic equator. In addition, auroral electrojets flow in the auroral belt and vary in amplitude with different levels of magnetic activity. The solar quiet fields are on the order of 10-50 nT, depending upon component, latitude, season, solar activity, and time of day. The magnetic signature of the equatorial electrojet can be about 5-10 times that of solar quiet; and that of the auroral electrojets can vary widely from 10-20 nT during quiet periods to several thousand nT during major magnetic storms. It is complex but the near-earth magnetic field has a significant predictable varying component and also a significant non-predictable varying component. For argument's sake, we will make the reasonable assumption that there is a 300-500 nT or 1% unpredictable component of the near-earth magnetic field. Accordingly, there is a 10 km varying uncertainty of where the target is relative to the beam.

3. PROPOSED SOLUTION TO COULOMB REPULSION PROBLEM

As indicated, computations for Coulomb repulsion for pulsed relativistic beams of 1000 amps over distances of 1000 km is most likely a classified subject. I have not seen anything in the literature on that but the general subject of Coulomb repulsion has been well characterized in the public literature for steady beams of nonrelativistic energy and currents of a few milliamps. See for example the thesis of Jansen[5]. According to Jansen, there are three components to Coulomb repulsion. These are 1) a test charge is deflected radially by the electric field (magnetic fields are ignorable at these low currents) due to the spread out position of the remainder of the beam, 2) the Boersch effect which produces a spread in longitudinal energy or velocity due to stochastic interactions of each electron with all the individual electrons in the remainder of the beam (producing chromatic aberrations downstream), and 3) a spread in transverse position due to stochastic interactions with the individual electrons in the beam.

It is well known that for a uniform current density beam, all electrons experience a net radially outward Coulomb force. But this does not necessarily hold true for a non-uniform current density beam. Is it also possible that the outward directed Coulomb force could be matched with initial inward directed momentum to compress the beam to a focus?

It occurred to me that the Coulomb repulsed beam could be run in reverse. That is, start with a parallel, uniform current density 1 cm diameter beam with 1 GeV energy and 1000 amps coming out of an accelerator. Let it propagate for 1000 km and note the distribution of position, angle and energy of the beam at the target. It will not likely be uniform in current density, angular distribution or energy. That is, the original parallel monochromatic beam will now have variations in energy as well as variations in directions of propagation. This is shown in fig. 2. Then, with that as a starting condition, reverse time and run the beam back. What would happen? I would say that the beam trajectories are reversible - or at least very nearly so. The 5 meter wide slightly converging non-monochromatic beam would converge to become nearly parallel, monochromatic and 1 cm in diameter at 1000 km as shown in fig. 3. The first component in Jansen's thesis is completely reversible. The second and third components are not reversible but will be smaller in reverse since the beam is far apart during the early part of travel so any stochastic terms will have less time to produce deflection than in the forward direction.

T. Groves also studied stochastic electron-electron interactions in conjunction with a lithography application[6,7]. Based on computations from Groves, the ratio of irreversible to reversible components of the Coulomb repulsion for the case at hand should be vanishingly small (approximately 10^{-15}) compared to the lithography application. As a conservative estimate, I consider the irreversible component to be of the order of 0.1 mm. If this is reasonably accurate, the electron optics of the proposed directed energy weapon is reversible and the method proposed here is valid.

With my deflection technology, steering a 5 meter wide beam without introducing aberrations is not a problem although the deflection angle will be limited due to the stiffness of the 1 GeV beam and the difficulties from the need to use very high deflection voltages. Figure 4 shows the schematic analogous to fig. 2.

What would such a beam weapon look like? Rather than a traditional particle accelerator as described by Parmentola and Tsipis, I envision a large electron gun 300 m in length and 5 m in diameter as seen in fig. 5. There would be 100,000 or more field emission tip electron sources arranged on a curved conductive surface aiming along trajectories that would fit the previously mentioned problem run in reverse. This is reminiscent of the Pierce gun with a concave shaped cathode[8]. To produce a 1 GeV beam, it would take 301 properly contoured plates with apertures arranged to passage the beams from all the individual field emission sources. The curvature of the plates is exaggerated in fig. 5. They are within a fraction of a mm of perfectly flat. Each of these plates would be 3.33 million volts more positive than the previous plate on the cathode side. The exit plate is at ground. Apertures in each plate are aligned to provide the proper trajectory as determined from fig. 2. Each plate would be separated by 1 meter from adjacent plates. The fields between the plates would be the same as an electron microscope that I built as a graduate student in 1970[9] (100 kV and 3 cm gap). Based on my experience, this field size is practical (and conservative) from high voltage breakdown considerations.

Getting a pulsed current of 1000 amps from 100,000 field emission sources requires a relatively modest 10 ma per tip. The gun is assembled in space. The plates are not mechanically connected one to another. They are each free to move under the control of small gas jets. Laser beams directed down alignment apertures guide positioning. There is no need for mechanically rigid high voltage insulators. While a sizeable engineering project, nothing seems unsolvable. To generate a beam with non-monochromatic energy distribution as starting conditions, the field emission tips could be at different potentials if the energy differences are small or even be placed on different curved plates if the energy differences are megavolts.

Although large in dimensions, the gun itself would not be massive since the main components (the 301 shaped surfaces) are not massive. The surfaces could be formed of thin metallic sheets or metalized plastic membranes for example. They could be folded or rolled up for transportation in a Shuttle cargo bay and unfolded into shape in space.

We would need to prevent charging of the device by draining off positively charged ions as the beam is operated. Charging capacitors and jettisoning positive plates in conjunction with the beam pulsing can accomplish this.

How would this device be powered? During the short time of operation, the beam has an enormous amount of energy. One thousand amps at 1 GV is 1000 giga watts. The energy in the beam is the power times duration of the pulse. For 0.1 msec pulses, this amounts to 100 mega joules per pulse. I envision energy storage in the form of a series of rotating flywheels that are coupled to generators. Each 3.33 MV power supply for each plate could have its own rotational energy storage setup which would solve the problem of how to power them while each is at a different high voltage. The rotational energy could be built up during times when the beam is idle and readily available for times of need. A reasonable rotational energy storage unit could be 10 to 100 kg rings 1 to 10 m in diameter and rotating at 100 to 1000 revolutions per second. While the gun is very large in physical dimension, the 300 flywheels (total of 3,000 to 30,000 kg) are the most massive part of the device by a large measure. This would result in the ability to provide up to 1 pulse per second continually for weeks. This device is shown in fig. 6.

Chemical power (pinwheel rockets), gas jets, or even solar power would get the storage wheels up to rotational speed. After this energy is built up, keeping it going requires continual and/or periodic re-injections of spin energy.

While definitely not trivial to design and build, this configuration seems to be a feasible solution to the first “impossible” problem of Parmentola and Tsipis. Now what about the second problem? How could this device be used to hit a target 1000 km away while the beam is deflected by dynamically changing near-earth fields 1000 km off a line of sight to the target?

4. HOW TO HIT A MOVING TARGET 1,000 KM AWAY

We have already arrived at the estimate that there would be a 10 km uncertainty in beam trajectory at 1000 km due to the unpredictable component of the near-earth magnetic ambient field. How could we hit a 1 meter target? There are several possibilities. Perhaps we could make a line shaped beam and sweep it in a raster fashion like a broom over the 10 km by 10 km field horizontally and then vertically. While doing this we can use infrared telescopes in orbit and/or earth based to look for sudden heating of the target or x-ray sensors to look for sudden x-ray flashes – in real time since as already said, the beam is travelling essentially at the speed of light. When a heat surge or x-ray emission from the target is detected, it can be correlated to the beam position so that the target could be located in short time.

There are other ways to solve this problem. We either need to know the magnetic field to 1 part in 10^7 between gun and target (mostly near the gun) or we can rely on an array of distant test targets that can be used for calibration. This is analogous to a target-shooter who can either know the wind between him and the target or take a few test shots for calibration. The first may be impractical for us but the second is not. The gun could send short bursts to test targets strategically placed and get feedback on magnetic deflection. We may not be able to operate during violent magnetic storms.

This device would not operate well in vacuum worse than 10^{-6} torr. There would be unacceptable corona. If the orbital environment is not that good, perhaps the entire gun can be contained within a polymer sleeve and pumped down to required vacuum levels.

There are other questions that are ignored in this treatment. To name a few, how many of these guns are needed to provide protection for the entire country from ICBM attacks? (According to Parmentola and Tsipis 150 would be needed.) How could these be used to knock down hundreds of incoming missiles with many decoys? How could this device be operated and controlled. How could this device be protected? Is it fragile or could it be considered a reliable weapon? There are many more such questions that need to be considered. However, the fundamental limitations seem solvable. In addition to protection from ballistic missiles, since electrons can penetrate some distance in air, this device might possibly be used to protect us from threatening high-flying aircraft. Could it also be used to protect offensive missiles?

One idea that may present more problems than it solves is to use an electron beam directed energy weapon in a geosynchronous orbit at 40,000 km altitude. The solved problem is that only a few devices are needed to protect the entire country. The new problem is of course, because of the further distance, Coulomb repulsion and the ability to hit a target are more difficult. However, if the problems described here can be solved for 1000 km distance from device to target, it is perhaps not unreasonable to say that the problems are also solvable for 40 times that distance.

5. E-BEAM LITHOGRAPHY, ANOTHER POSSIBLE APPLICATION

There has been a long running technical competition between systems that use photon optics and other systems that use electron optics, x-rays or mechanical imprints to make the next reduced feature size computer chips. Diffraction due to the relatively large wavelength of light is the major limiting problem in photon optics. With ingenious methods, engineers have devised machines that reliably make features half the size of light wavelengths and have gone deep into the ultraviolet to obtain smaller wavelengths. Some but certainly not all people expect this to eventually cease since the wavelengths used now are so far into the ultraviolet that few optical materials exist that can transmit light sufficiently to make lenses. The limitation in electron optics is not wavelength, since that is very small, but rather Coulomb repulsion can be the limiting factor. One simple way to reduce Coulomb repulsion beam spreading is to reduce the beam current. However, with lower beam current, it obviously takes longer to write the features on a chip. Thus the ramification of Coulomb repulsion in lithography is to increase the time it takes to make a microcircuit pattern or decrease throughput. The technology described here might be miniaturized - perhaps by nanotechnology. If so, perhaps these methods could apply in lithography.

6. CONCLUSIONS

The weapon described here may never be built or, taking a more optimistic viewpoint, we may not even need such a device to protect our cities and ourselves. That would be the desirable situation. However, the world is more dangerous again after a period in which this was abating. The defensive weapon described here is an extreme device, to be sure, but I think that it can now be moved from the impossible realm to the very difficult but not impossible realm.[10]

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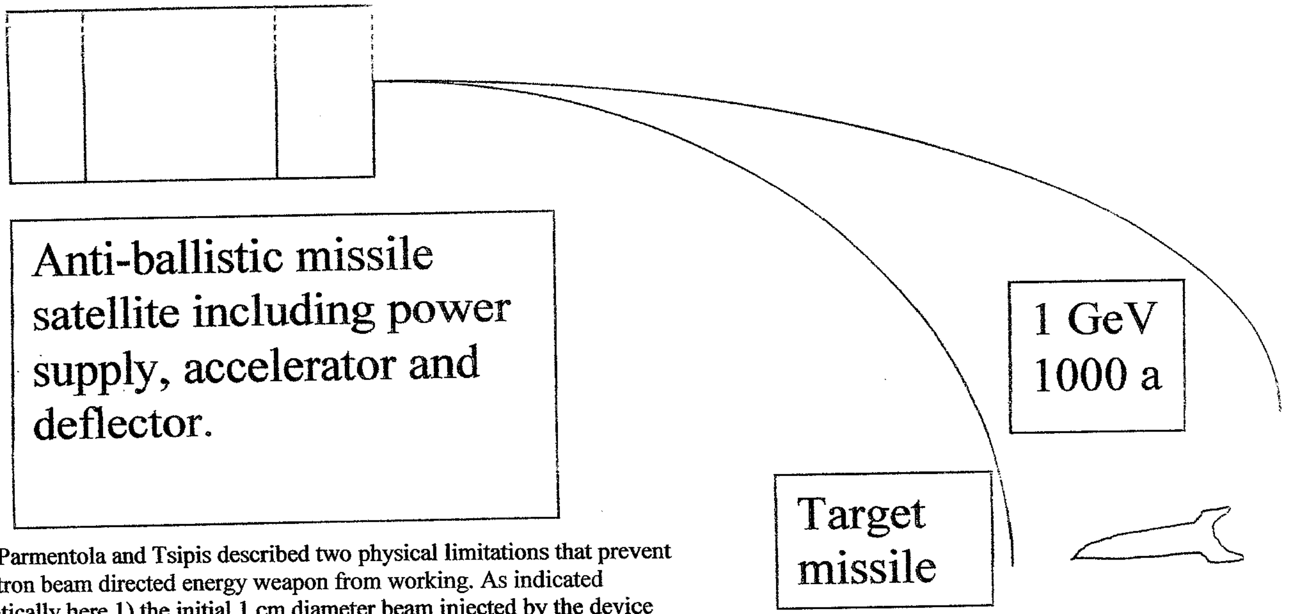

Fig. 1. Parmentola and Tsipis described two physical limitations that prevent an electron beam directed energy weapon from working. As indicated schematically here 1) the initial 1 cm diameter beam injected by the device spreads to an unacceptable 5 meter diameter at operational distances of 1000 km and 2) the beam is deflected 1000 km by the unsteady near-earth magnetic field.

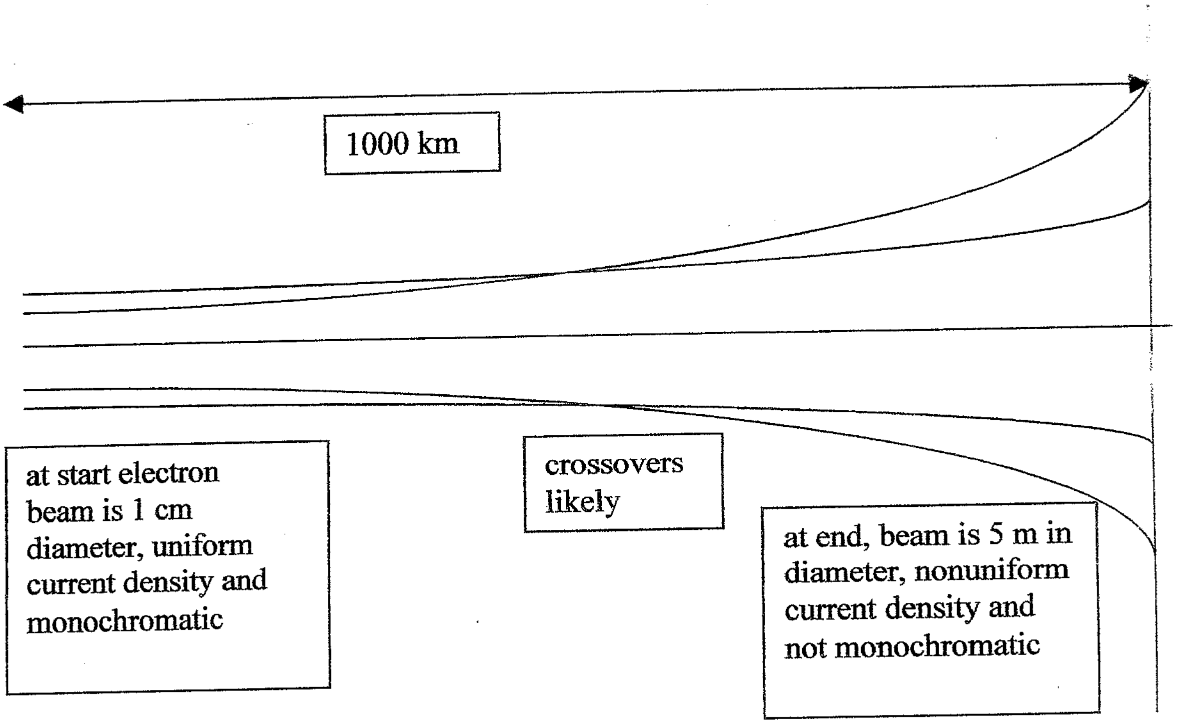

Fig. 2. Trajectories of representative electrons in a 1000 amp beam at 1 GeV that propagates for 1000 km. The beam is initially 1 cm in diameter but spreads to 5 m diameter due to Coulomb repulsion.

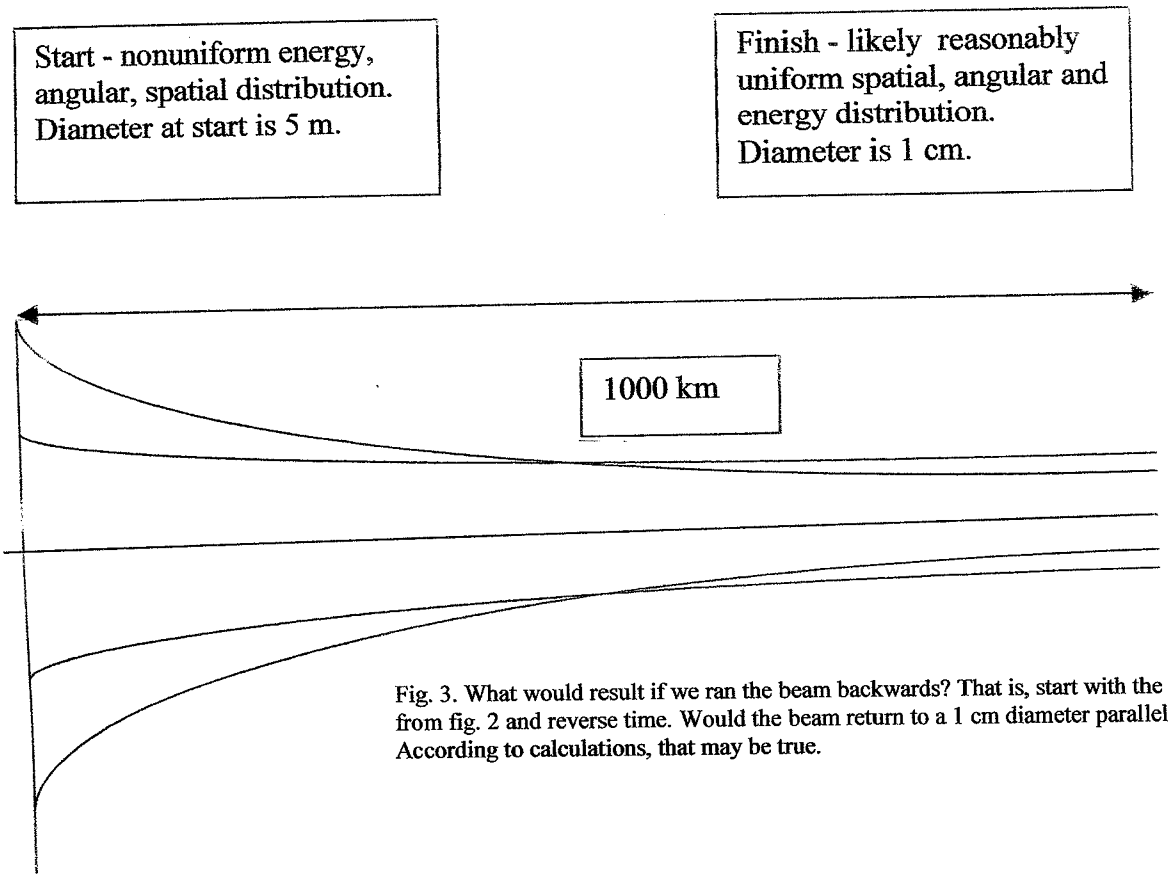

Fig. 3. What would result if we ran the beam backwards? That is, start with the end results from fig. 2 and reverse time. Would the beam return to a 1 cm diameter parallel beam? According to calculations, that may be true.

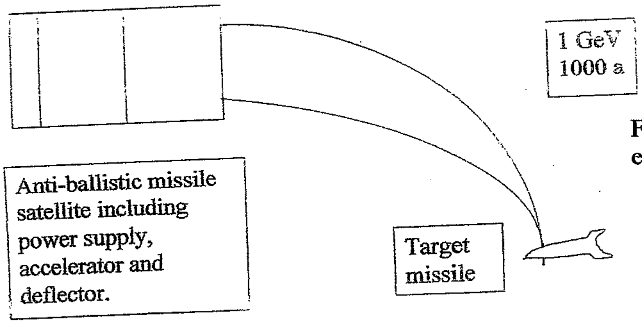

Fig. 4. If the beam is reversible as in fig. 3, an anti-missile electron beam directed energy weapon might work as shown.

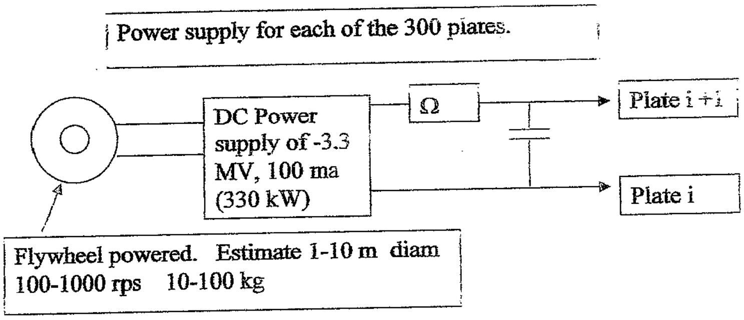

Fig. 6. Energy stored in flywheels is perhaps the ideal way to power each plate.

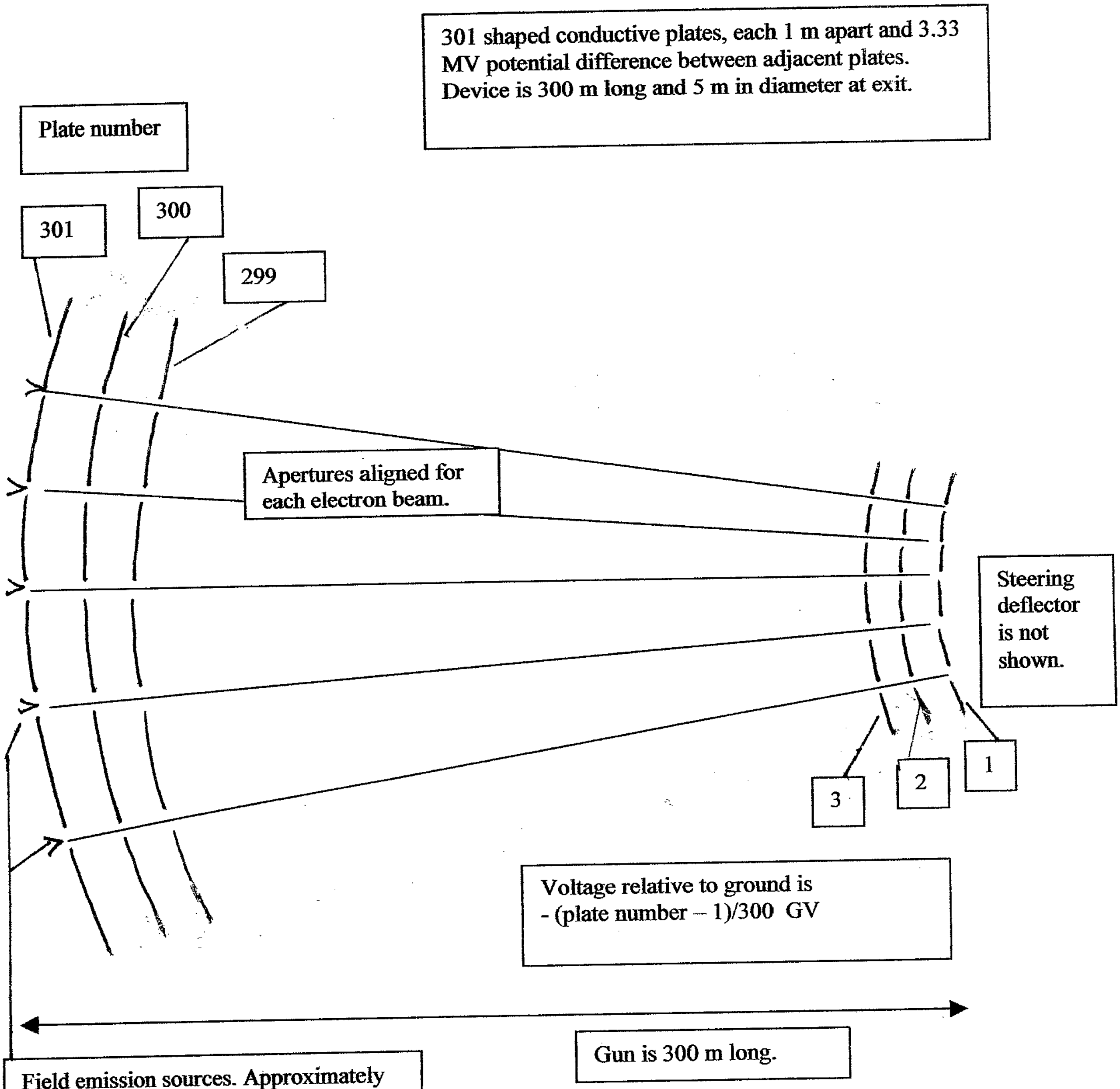

Fig. 5. The electron gun for the directed energy weapon. Only the first few plates and last few plates are shown. The plates are not mechanically connected. Positioning and alignment is measured optically and motion is provided by gas jets attached to each plate.