An Active Particle Accelerator

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Abstract

Although a static charge is difficult to maintain on macroscopic particles, it is straightforward to construct a small object with a regularly oscillating electric dipole moment. For objects of a given size, one may then construct an accelerator by appropriately matching the frequency and separations of an external array of electrodes to this size. Physically feasible size ranges, an accelerator design, and possible applications of such systems are discussed.

Introduction

Most particle accelerators[1] use electric fields to accelerate a particle of fixed charge; an electron or ion. Some have been used to accelerate small charged macroscopic bodies (dust particles[2]). In these cases, the particle is entirely passive. Once ionized, one depends on the fixed intrinsic charge for atomic or subatomic particles.[3] For the small macroscopic bodies, high vacuum must also be employed to prevent changes in charge to the extent feasible. This does not appear to be feasible for large macroscopic objects due to self-ionizing effects which limit the amount of charge that may be held on the object, by limiting the electric field strength at its surface or by absorption of other free charges.[4] However, these considerations may not apply so stringently to electrically **polarized** bodies if this polarization varies in time.

Thus, another class of electromagnetic accelerators may be considered. These are ones in which the accelerated particle (definitely **not** elementary) includes a power source and circuitry which can vary its electrical properties as a function of time. The case of linear magnetic motors[5] may be viewed in this way if the changing magnetic field is generated in the moving object in addition to, or rather than, in the roadbed. (Static fields on board do not qualify as representations of the effect we have in mind, not even the approximately constant currents in rail guns[7].) This concept of an active accelerated particle may also be applied to electrically polarized objects as we now show. The following may by no means be the optimal configuration. Rather, it is only intended to provide an existence proof by construction.

Basic Design

Consider a small but macroscopic particle of length d. For convenience, let it be a hollow ellipsoid of revolution, made of an insulating material. We will coat the tips with a conducting material, and attach wires (waveguides if necessary) from the interior through the surfaces to contact these conducting tips. In the interior is a power supply (battery) and oscillator circuitry to produce the highest feasible voltage difference between the tips varying at a frequency f.

Let this active particle be injected, with its oscillator at a specific phase, into an accelerator consisting of a series of conducting rings driven at a frequency

$$F = \frac{1}{2}f$$

with alternate rings connected to opposite sides of the driving oscillator. The ring separation, D, must be greater than d, and equal to the distance travelled by the active particle at its instantaneous velocity, v; that is

$$D = \frac{2\pi}{f}v.$$

The latter condition may be achieved by increasing D gradually, or changing f and F. The first method is initially simpler, but ultimately must lead to a decreasing accelerating field strength as the ring separation grows. The latter requires a precisely programmed frequency shift or active communication with the particle inflight (see below). The acceleration process is depicted in the Figures.

Notice that the oscillating polarization is in no way equivalent to a rotating electrostatic dipole. In that case again, the fixed charges will sooner or later attract others to neutralize them. Only the forced dipole charge oscillation keeps stray charges from accumulating and neutralizing the charge separation needed for acceleration.

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Acceleration Scale

Since we are considering acceleration of macroscopic bodies, the time scales involved are likely slow on the scale of electromagnetic phenomena. Thus we assume only modest potential differences, say of order 5×10^5 V, between the accelerating electrode loops separated by perhaps 20 cm., and do not depend on sophisticated time dependences[6] to prevent arcing and breakdown. More modest voltage differences, say 2×10^4 V may be achieved across the smaller but comparably sized, say 5 cm in length, active particle. With these voltages setting the scales, we find accelerating forces greater than 0.5 N to be entirely conceivable. For active particle masses of order 10 g, this corresponds to accelerations of order 50 m s^{-2}. Larger forces and accelerations may well be possible.

Injection

Presumably there is a natural minimum velocity at which this acceleration process becomes practical or feasible. Since the acceleration region would preferably be evacuated to minimize drag at the desired high end velocities, it seems natural to consider compressed gas as the initial acceleration mechanism. The excess would be pumped off at the first pumping station at the low velocity end of the accelerator. This might be aided, for example, by a 'choke' just large enough for the active particle to pass, and defining its initial acceleration location, centered in the accelerating loops.

Stabilization

Of course, the accelerator we have described may not be stable. Appropriate feedback and stabilization mechanisms must be employed to keep the active particle centered in the accelerating loops, as well as longitudinally in phase with the linear accelerating fields.

Transverse stabilization is very different here from that needed in accelerating a disconnected collection of charges. It is not sextupoles or octupoles that are needed here to reconverge straying dipolar particles. Rather, the entire object must be constrained to avoid crashing into the edges of the acceleration loops. Spin stabilization (rifling) probably remains the best initial prospect for transverse stabilization of macroscopic bodies. This may be achieved, for example, by means of lightweight tailfins responding to a transverse air circulation just before injection commences. These may then be sheared off at the 'choke' at the end of the compressed gas injection region, if they would interfere with the later acceleration process.

For longitudinal stabilization, one needs to sense the location of the active particle in the accelerator. For this, it is entirely conceivable that the standard phase stabilization procedure is still applicable, trading off some accelerating voltage for increased stability. By choosing a point slightly off (ahead of) the maximum interelectrode voltage in the oscillator cycle, the active particle receives a stronger boost if it is a little behind where it should be for matching to the next section, and a little weaker boost if it is a bit ahead.

In the longer term, one may find it more convenient instead to communicate with the active particle[8], locating it by its reflection of laser beams, and by transmitting, between acceleration loops, commands to its oscillator circuitry by encoded light pulses sent to a receiver circling its middle.

Additional Considerations

What is the useful size range of active particles for such accelerators? If the active particles can be made microscopic, we can imagine filling hollows in it with tiny doses of chemicals, or radioactive materials for biological injections from large (safe) distances. At the other extreme, one can consider perhaps more efficient alternatives to the magnetic rail gun concept, and with less constraint on the mass and structure of the accelerated object, driving significant massive bodies to orbital velocities. Between these extremes lies a large range of interesting possibilities. Of course, it is necessary first to make a proof-of-principle working prototype, even if only of a few stages of acceleration. This has not yet been accomplished.

References

[1] *Principles of Charged Particle Acceleration*, by Stanley Humphries, Jr. (Wiley, New York, 1986).

[2] P. W. Keaton, *et al., Int. J. of Impact Engng.* **10**, 295 (1990).

[3] See for example, A. Septier, in "Proceedings of the International Conference on Multiply-Charged Heavy Ion Sources and Accelerating Systems (Gatlinburg, TN, 25–28 Oct. 1971)," *(IEEE Transactions on Nuclear Science*, **NS-19**, Apr. 1972), p. 28.

[4] See for example Sec. 9.5 of Ref. 1.

[5] H. H. Kolm and R. D. Thornton, *Sci. Am.* **229**, 17 (1973).

[6] *4th Symposium on Electromagnetic Launch Technology (Austin, TX, 12–14 April 1988)*, (IEEE, New York, 1988); but see also H. Kolm and P. Mongeau, p. 34; F. Winterberg, p. 160; O. K. Mawardi, p. 184, in *2nd Symposium on Electromagnetic Launch Technology (Boston, MA 10-13 October 1983), (IEEE, New York, 1984).*

[7] See Sec. 14.5 of Ref. 1.

[8] See paper by Mawardi in Ref. 6.

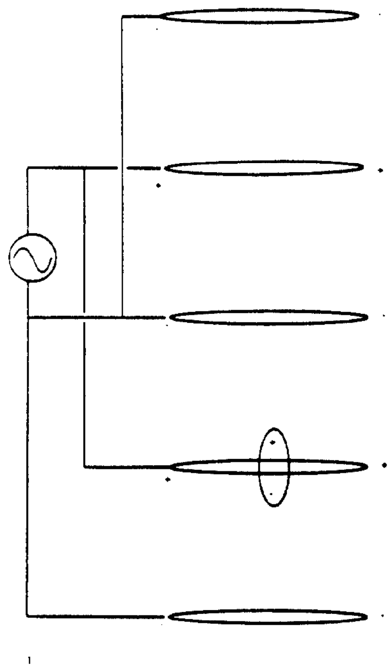

Figure 1. A maximum field strength configuration. The accelerating loop electrodes are ϵ° before the maxima in their oscillator cycle. The active particle is at maximum in its oscillator cycle. Accelerating force is at maximum.

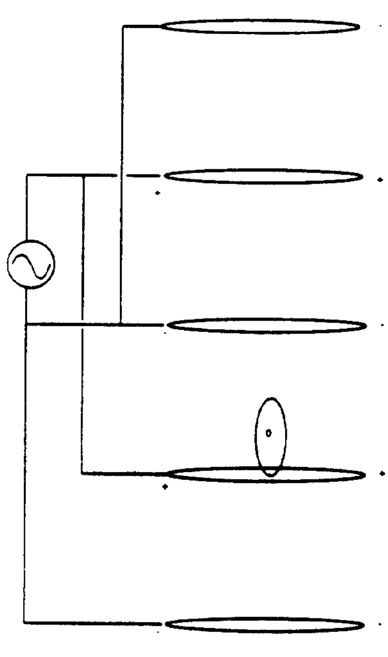

Figure 2. The voltage difference across the active particle is zero, but the accelerating loops are only $(45-\epsilon)^{\circ}$ through their cycle, with a voltage reduced from maximum by a factor of almost $\sqrt{2}$.

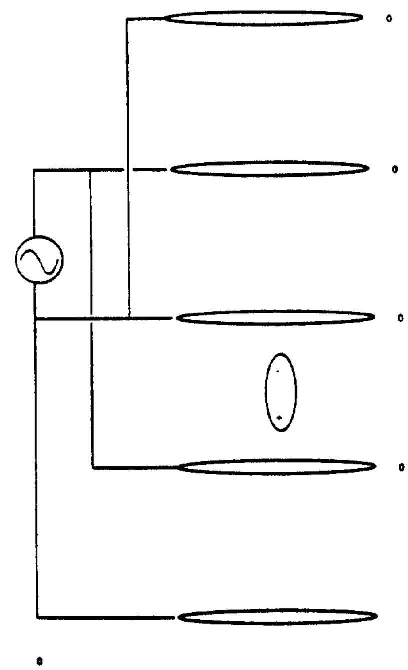

Figure 3. The accelerating loops have almost zero voltage, and the active particle is at maximum reversed polarization.

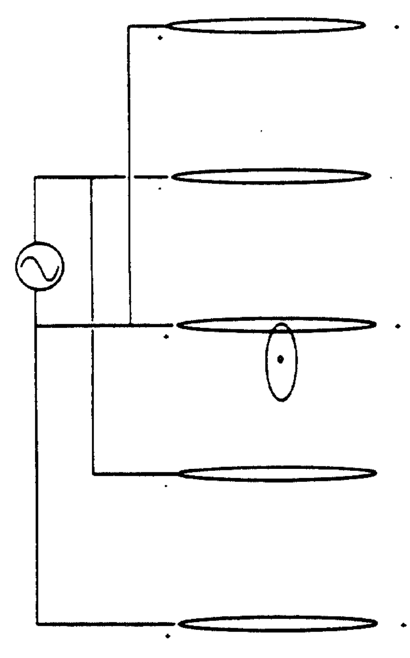

Figure 4. As in Figure 1, but with accelerating loop voltage increasing.