PERSPECTIVES OF LASER ACCELERATION BY PLASMOIDS IN RF WELLS

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Abstract

Collective laser acceleration by plasmoids in moving RF wells (HF traps) differs from the popular methods based on plasma waves by using forced oscillations of plasma instead of free ones, *e.g.*, wake fields. A similar way is used in classic resonant accelerators and FELs. It simplifies the plasma problems at the price of large power of feeding lasers. Some results and perspectives are discussed.

1 INTRODUCTION

Several groups investigate accelerators based on plasma waves, which are excited by powerful short pulses (*e.g.*. [1] and references therein). These schemes are based on ***free*** (resonant) oscillations of the plasma and hence they directly depend on the plasma tolerances and instabilities.

The present variant of acceleration is based on ***forced*** oscillations of charged plasma in laser-generated moving or standing RF wells (HF traps, ponderomotive- or quasipotential wells, M.A. Miller's force, light pressure, -see [2]). It leads to several schemes of laser acceleration, based on far field, with small dependence on plasma parameters. Realization of one of them, namely MWA (moving well accelerator, -[3-5] and references therein), is possible on the base of a terawatt table-top laser. This scheme and its future are discussed in this report.

RF wells (small "carrier wells" and large "envelope wells") may be distant from the radiating surfaces, hence the electric breakdown problems are moved aside, and concentrated fields with high amplitudes may be used. RF wells are effective, if the field amplitude is high, $E_m \sim$ mc$^2/e\lambda$, *e.g.*, 1 TV/m in case of electrons (positrons) and a 1-μ m laser.

This effect may be treated as 3-dimensional AG focussing of the electron component of plasmoids. The computed dimensions of plasmoids in case of carrier RF wells in a cylindrical wave $E_{0mn}(\varphi, r, z)$) are ~λ/6 or smaller, and their density is sub-critical, $n \approx 0.01 n_c$, so they are ~Debye length. It simplifies the plasma stability problems.

Motion and acceleration of an RF well takes place, if a given structure of its field in the moving frames is generated by corresponding laboratory sources.

2 THE SCHEME OF THE EXPERIMENTAL ACCELERATOR

Its field structure is based on A.M. Sessler's idea [2] to use crossed beams of a small laser instead of expensive system of oversized converging resonators with kilo-Joules of stored optical energy. The RF wells exist in many points in the zone of intersection of the focused laser beams.

These beams are scanned by 2 dispersion cut cones (for higher accelerating gradient) or by 2 pairs of 4 segments (for larger number of particles, Fig.1). The programs of the frequencies and angles variations are defined by Lorentz-transformed values of the RF well parameters, E_m, ω, θ, given in the moving frames. The frequency ω may be constant, but the variation of the angle θ, *i.e.*, of the RF well form, is limited near 45 ± 15^o. The sources of these beams are 8 focused dispersion segments at the Fig.1 in 8 symmetric points ($\pm x_1$;0), (0;$\pm y_1$), ($\pm x_2$;0) and (0;$\pm y_2$), or 2 cut cones.

The scanning of the beams during the acceleration is realized by linear transforms of the laser pulse. It is split into a pair of pulses, each of them is stretched and frequency-modulated (FM, chirped) by means of positive and negative dispersion elements ±D (and split again in the case of 8 segments) .

The lags of ion centers from electron centers of plasmoids and of the latters – from RF well centers must be small (say, ~0.01 λ), if the number of accelerated ions must be large. Larger lag gives higher acceleration. Excess of electrons ensures the capture of ions. Adequate values of the angles of scan in this "scanator" (say, 0.01 rad per chirp 0.2 %) may be reached by means of chromatic elements with high spectral resolution (transparent or reflector echelons).

Comparison of this "scanator" with the scheme [6], based on free plasma waves, shows the absence here of the problem [6] of ~50 % FM, and of the plasma density precise variation synchronized with the FM.

Future development may include recuperation resonators for repeated use of the laser pulses, and wide "envelope" RF wells The next possibility of development is the use of MWA accelerator based on several sections of oversized converging wave guides activated by pairs of frequencies with longitudinally growing difference [2].

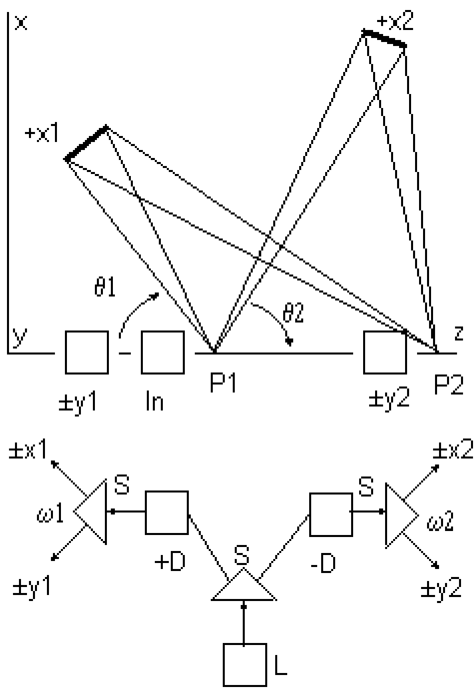

Fig 1. Scheme of the scanator.

The injector (**In-** Fig.1) may be simply a gas jet similar to that used in printers.

Estimated parameters of a proof-of principle model proton accelerator are given in the Table 1 below:

Table 1. Some parameters of the scanator model.

Laser pulse energy/duration	40 J/1 psec
Laser wavelength	~1 mkm
Radii of scan	50 cm
Length of the acceleration path:	1 cm
Maximal angles of scan	~0.01 rad
FM deviations:	0.2 %
Number of RF wells in the focal region :	~ 200
Focal field density	200 GV/m
Acceleration gradient	~1 GeV/m
Neutralization factor	~0.8

The number of accelerated ions per plasmoid is defined by the ion density and plasmoid volume, and it is $\sim 10^{-5}\ \lambda / r_e$, r_e being the classic radius of an electron. The accelerated current does not depend on the wavelength λ (at a given relative density n/n_c).

The state of the art of petawatt lasers and progress in optics gives hope on the realization of this scheme.

This variant of the "scanator" is based on the relatively small "carrier RF wells", which are disposed with z-intervals equal to a half of the z-wavelength.

Wide "envelope" RF wells in slowly varying fields [2] may decrease losses of particles.

3 RESULTS OF NUMERICAL STUDIES

The axially symmetric relativistic motion of many interacting and radiating electrons and protons was modeled in the *rz*-plane by the PIC method (C++ language; 2.5 measurements: r, r', z, z', and the full velocity; rectangular toroidal macroparticles). Full system of Maxwell's equations and equations of the motion was solved for electrons and ions in the co-moving (with the accelerated plasmoid) ideal cylindrical resonator (with a radius R) tuned to the wave E_{011}. The number of macroparticles in the calculations was usually ~50 000, the grid sizes about 30×30. The use of moving frames leads to much economy of computation time. Special checks (longitudinal waves in tubular beams, transverse waves in plasma columns, several modes in an empty cylindrical resonator) have shown the precision better than several % for the present case, when the plasmoid is relatively small, $\sim\lambda/6$ or less. The parameters in the multi-particle case are the field amplitude, Brillouin angle, initial acceleration, initial densities of electrons and protons and some computational parameters (the numbers of computation cells and steps per RF period, *etc*). Preliminary values of the densities were chosen with the account of Kapchinski — Vladimirski equilibrium and its stability studies, which limit the AG focusing depression by the space charge up to ~30%. But the initial conditions were uniform density and zero velocity for electrons (m) and ions (M_i), which lead to non-uniform density and losses ~20% of the particles -at the initial several hundreds of periods.

. Some computed shots of electrons (upper half-bunches) and ions (lower half-bunches) are shown at the Fig-s 2-3 for the times 79977 and 650007 time units *λ/33c*. The initial distribution of electrons and protons was chosen (for the economy of cells) as a neutral spheroid, corresponding to the RF well dimensions found in the preliminary 1-particle modeling. Fig.4 shows the numbers of electrons and protons in the accelerated RF well as functions of time units λ/2.2*c*): after an initial relatively swift (~2000 time units) loss the self-consistent evolution process leads to acceleration of the particles during ~25 000 periods with a relatively slow loss. The form of both bunches, electron and proton, is gradually normalized, and a slow "evaporation" of particles takes place. This process is similar to halo formation in the case of RFQ linac. The acceleration gradient $10^{-6}\ M_i\ c^2/eR \cong 2$ GeV/m found in the modeling, corresponds to a simple estimation for 2 intersecting ($\pm$) charged spheres with the modeled densities and radii.

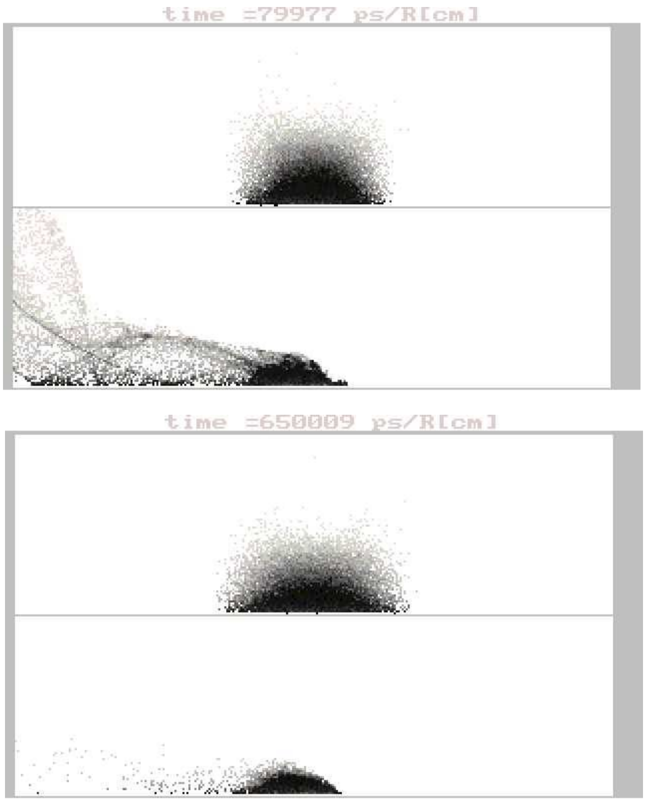

Fig 2-3. r-z portraits of electrons and ions in an accelerated RF well

The computed cartoons show the AG focusing-defocusing *r*-*z*-oscillations, as well as the lag of accelerated ions from electrons, and of the electrons – from the RF well center. Optimal amplitude of the field was found to be $E_m \approx mc^2/R\,e$, where R is the radius of the resonator, $R = 2.2\lambda$ for the present case of Brillouin angle $\theta \approx 60^\circ$, *e* is the electron charge.

The number of accelerated particles per plasmoid was found to be ~3000 electrons and ~1000 protons.

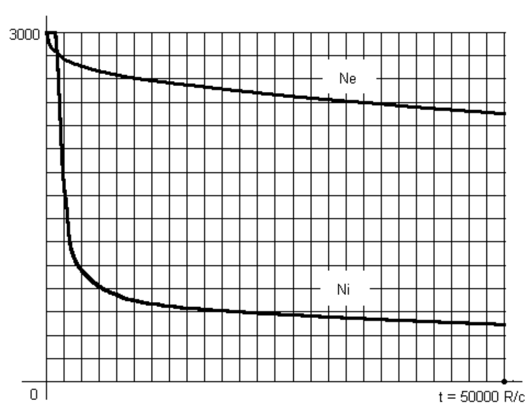

Fig.4. The numbers of accelerated particles.

The optimal acceleration value $0.000001\,c^2/R$ corresponds to the acceleration gradient ~1 GeV/m.

4 CONCLUSION

A compact proof-of principle collective accelerator (“scanator”) may be built on the base of a table-top terawatt laser and a passive optical system, which transforms the laser pulse into a pair of chirped pulses.

After passing through the dispersion system the scanning light beams arise.

The ions are accelerated by the electron component of plasmoids (short plasma bunches), which are trapped by moving RF wells of the electromagnetic field in the intersection region.

This region is periodically scanned along the line of acceleration. An estimation of parameters of a model shows the possibility of acceleration of protons from a gas jet to ~10 MeV on a way ~1 cm.

Recuperation optical resonators will give higher efficiency. Wide envelope RF wells (in slowly varying fields) may decrease losses of particles defined by the Gaussian halo, and increase the acceleration gradient and the number of particles.

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