Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

POSSIBLE ENERGY INCREASE OF HIGH CURRENT ELECTRON ACCELERATORS

A.Ts. Amatuni, S.G. Arutunian, S.S. Elbakian, M.R. Mailian, M.L. Petrossian
YERPHI, Yerevan, Armenia.

Abstract

Proposal for investigation of the possibility to obtain compact, effective high current electron accelerator for medium energy range using plasma wake field acceleration (PWFA) mechanism is presented. The goal of proposed investigation is not an achivement of highest possible acceleration rate, but effective increase of the energy of high current $(\sim kA)$, low energy $(\sim 2MeV)$ electron accelerator, due to interaction of electron bunches with plasma wake waves.

1 INTRODUCTION

Plasma based advanced accelerator concepts have been developed mainly in order to obtain high accelerator gradients for furure linear colliders in the TeV energy range. But, simultaneously, the variety of the other possible applications also have been developed. In the recent review [1] some near-term and long-term applications of plasma-based accelerators have been mentioned and discussed.

In the present work the project for investigation of the possibility to obtain compact, effective high current $(\sim kA)$ electron accelerators in the medium energy range 20-200 MeV, using plasma wake field acceleration (PWFA) mechanism, is considered. Existing electron accelerators for energy 20-200 MeV have average accelerated current not more than a few milliamper. So the problem of creating the accelerating installation for electrons with energy of order 100 MeV, with pulse current $\sim 100A$, repetition rate $\sim 100Hz$, macropulse duration $\sim 1\mu sec$ and bunch duration $\sim 0.1nsec$ is an actual one.

Up to now the ordinary known accelerator technologies have been unable to create the accelerators with above mentioned parameters. Such kind of accelerators must be of common use and can have wide applications in material science, generation of X-rays and soft gamma rays, possible use in inceneration of some radioactive wastes[2] and others[1].

It seems at the first glance, that an additional acceleration, which can be provided by plasma wake waves, generated by electron bunches from high current $(\sim 1kA)$ electron accelerators with energy $(\sim 1MeV)$, could be used as a basic physical concept for creating compact, effective, economicaly reliable accelerator installations, with the needed range of the parameters.

The goal of the proposed investigation is not an achivement of highest possible acceleration gradient, but effective increase the energy of high current $(\sim 1kA)$, low energy $(\sim 1MeV)$ electron beams, due to interaction of electron bunches with plasma wake waves, generated by the beams from the same electron accelerator. The goal is to identify and to develop techniques, which may lead to more efficient, compact and inexpensive high current particle accelerators for medium energy range. Of course the increase in the energy will at the same time reduce subsequently the accelerated current, but it still can be large enough (for example, if initial energy is 1 MeV and initial current 1kA, the final energy could be $\sim 10MeV$ and final accelerated current $\sim 100A$).

The proposed work has some theoretical and experimental foundations, created by previous numerous investigations of PWFA (see, for example, a recent reviews[3], [4], [5]). Proposed work is going further than proof-of-principle experiment, it must be acomplished by the creation of the pilot installation (or test facility) and by the project of high current $(\sim 1kA)$ and medium energy $(\sim 100MeV)$ electron accelerator. This goal needs some additional physical as well as technological considerations and investigations, which will be briefly described in the following sections.

2 PROBLEMS OF PHYSICAL CONSIDERATIONS

Plasma wake wave acceleration (PWFA) of high current electron beams posed the problems, which are at some extent different from the problems, encountered in the investigations of physical ground of high energy plasma based linear colliders. High luminocity demand, determinating the main features of high energy linear colliders, for its realization needs very narrow bunches, when the transverse dimensions of the bunches are much smaller than plasma wave length. It is not the case for accelerated high current electron beams, where the transverse dimensions of the accelerated beams can be large enough, like in the induction linacs,and if the plasma density is high, in order to obtain high acceleration gradient, the transverse dimensions of the electron beams can be of order or even larger than plasma wave length. The last case opens the possibility to use, as a guiding tool, an one-dimensional approximation in theoretical consideration (see for example exact results, presented in [6]). It means, in particular, that it is possible to obtain high enough accelerating gradient and transformation ratio, when driving bunch parameters (charge density, length, Lorentz factor) are choosen at such a way, that wave breaking phenomenon in plasma wake wave can occure[7], [8]. But, in contrast to narrow bunches case, the blow out regime which is proposed as one of the candidates for nonlinear acceleration mechanisms for future linear colliders[9] is not realized for wide bunches, which will be used in considered case. Hence wave breaking phenomenon originated by wide driving bunches must be the subject of more careful theoretical investigations and for different sets of parameters of plasma- electron bunch system it must be discovered and investigated experimentaly too.

Plasma wake wave acceleration mechanism can be realized experimentaly by using different driving and witness bunches[10], one long driving bunch or sequence of short driving bunches[11], one bunch with nonuniform charge distribution, when rear part of bunch is selfaccelerated in the field, generated by the bunch head part[12],[13]. The choice of the optimal conditions for investigated PWFA process for high current beams is an another essential physical problem of the proposed work.

Wide bunches with nonuniform tranverse charge distribution, as preliminary nonlinear calculations show, presents the problem of transverse nonlinear instability, connected with plasma wave filamentation. It means that driving bunches must be transversaly uniform at some extend, which must be predicted theoreticaly.

There exist, of course, some problems which are common to that of high energy plasma based linear colliders, e.g. the problem of energy spread and acceleration efficiency, stability of driving and accelerated bunches, value and preservations of the emmitance of accelerated bunches, plasma chamber boundaries, influence on acceleration process and others.

These problems have to be solved at the conditions typical for high current acceleration purposes - i.e. when bunch transverse dimensions are of order or larger than plasma linear wave length.

All these problems must be considered and investigated theoreticaly and experimentaly. For theoretical investigation some approximate methods must be developed as well as a suitable programms for effective computer simulations. For experimental investigations the need for flexible enough (accelerator) test facility, with high current and low energy, long and wide enough plasma chamber with variable plasma electron uniform density are urgent.

3 OUTLINE OF TEST FACILITY

The test facility will be based on high current direct action accelerator fed by Marx generator and with photocathode. The electron energy is 2 MeV and pulse current up to 1kA. The outline of experimental installation is presented on Fig. 1.

The essential part of proposed installation is laser photon bunch shaping device, which allows to change driving electron bunch length, tranverse dimensions, bunch charge value and distribution, witness bunch delay, charge and dimensions, and also allow to originate a sequence of driving bunches.

The fourth harmonic of Nd: YAG laser is used. Pulse power for cooper cathode is 2MW, pulse energy by order of magnitude is $5 \cdot 10^{-4}$J. taking into account the losses, caused by harmonics transformation, the laser must have pulse power $\sim 10MW$ and pulse energy $\sim 1mJ$. On proposed installation it will be possible to investigate different mechanisms of plasma wake wave acceleration and find out

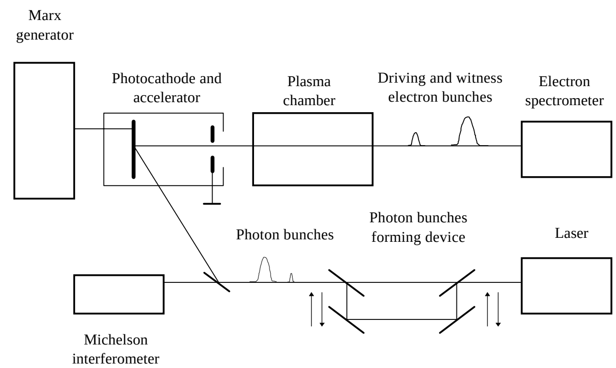

Figure 1:

the optimal one for high current wide electron beams.

Plasma chamber will be constructed using the experience gained at YerPhI during the last years, when different kind of plasma chambers have been constructed, tested and used in experiments. The plasma chamber will be 1m long, 20cm in diameter, with plasma density varied in interval $10^{10} - 10^{13}cm^{-3}$.

The main parameters of proposed test facility are given in Table 1.

Table 1

Initial energy of electrons	1.5-2.0MeV
Energy of accelerated electrons	$\sim 10MeV$
Driving bunch current	1kA
Accelerated electrons current	up to 100A
Electron bunch length	$\geq 3cm$
Electron bunch diameter	$\geq 1.0cm$
Distance between bunches	$\geq 3cm$
Driving bunch density	$2 \cdot 10^{10} - 2 \cdot 10^{11}cm^{-3}$
Plasma electron density	$10^{10} - 10^{13}cm^{-3}$
Plasma chamber length	100cm
Plasma chamber diameter	20cm
Laser pulse power	$\geq 10^8W$
Laser wave length	$0.266\mu m$
Laser repetition rate	1-10Hz

4 CONCLUSION

The proposed work pursued the following goals:

1. Theoretical investigation on PWFA mechanisms for high current wide electron bunches, taking into account wave breacking phenomenon, driving bunch

longitudinal and transverse dynamics and stability, focusing, emmitance preservations, energy spread, beam loading and others.

2. Construction and operation of the test facility.

3. Experimental investigation of PWFA mechanisms for high current wide electron bunches and determination of the optimal conditions for high current electron beams acceleration.

4. Research, development and preparation of the project of high current electron accelerator, based on plasma wake field acceleration mechanism, with accelerated electron energy 100MeV and pulse current 100A.

The described proposal will be presented for grant to International Science and Technology Center (ISTC) as a continuation of Project A-013 ISTC, which is realizing now at YerPhI.

5 REFERENCES

[1] T. Tajima, P. Chen NIM, Sec. A, A**410**, 344, (1998).

[2] S. Tőyama, Y.L. Wang et al., PAC'93, May, 1993, Washington D.C, USA.

[3] Ya. B. Fainberg Fizika Plasmi, **23**, 275, (1997).

[4] A. Ogata Beam Dynamics Newsletter, No 12, 34, (1996).

[5] E. Esarey et.al IEEE Trans on Plasma Sc. **24**, 252, (1996).

[6] A.Ts. Amatuni, S.S. Elbakian, E.V. Sekhpossian, R.O. Abramian Part. Acc. **41**, 153, (1993).

[7] A.I. Akhiezer, R.V. Polovin JETP **3**, 696, (1956).

[8] J.M. Dawson Phys. Rev **113**, 383, (1959).

[9] J. Rosenzweig, N. Barov, A. Muroch, E. Colby, P. Colestoek NIM, Sec. A, A**410**, 532, (1998).

[10] J.B. Rozenzweig, D.B. Cline, B.Cole, H.Figeroa, W. Gay, R. Konecny, J. Norem, P. Schoessow, J. Simpson Phys. Rev. Lett. **61**, 98, (1998).

[11] A.M. Kudryavtsev, K.V. Lotov, A.N. Skrinsky NIM, Sec. A A**410**, 388, (1998).

[12] A.Ts. Amatuni Proc. PAC'97, p. 693, (1997).

[13] R. Assman, P. Chen, F.J. Decker, R. Iverson, P.Raimondi, T. Raubenheimer, S. Rokhi, R. Sieman, D. Walt, D. Wittum, S. Chattopadhyay, W. Leemans, T. Katzouleas, S. Lee, C. Clayton, C. Joshi, K. Marsh, W. Mori, G. Wang NIM, Sec. A, A**410**, 396, (1998).