

A CW HIGH POWER AND HIGH QUALITY ELECTROSTATIC ACCELERATOR FOR FEL  
DEVICES

I. Boscolo<sup>+</sup>, G. Brautti, V. Stagno, L. Tecchio<sup>++</sup> and V. Variale  
Dipartimento di Fisica dell'Università e INFN-Sezione di Bari  
Via Amendola, 173  
70126 BARI

In this paper we present a study for a CW high power and high quality electrostatic accelerator. The energy and charge recovery of a high intensity electron beam is foreseen to be better than 99%. The multiampères beam leaves around 1% energy in a Free Electron Laser interaction and its normalized emittance is consequently worsen. The most relevant problems of high efficiency low losses transport and recovery are analyzed and solved.

### Introduction

A high power and quality electrostatic accelerator capable to recover an energy spreaded electron beam could be very interesting for several applications. For a millimeter-FIR high power FEL the major problem is the electron source. It's required, indeed, a good quality electron beam (eb), a current of a few ampères and an energy of some MeV. For CW laser operation the eb must be continuous [1], thus an electrostatic accelerator has to be used. Furthermore, among the electrostatic accelerators we need the one that can supply very high power to the high voltage terminal.

A detailed analysis of the electrostatic accelerators has done in ref. [2]. The so called electrodynamic machines (Dynamitron, Transformer accelerator and Transmission Line generator) are suitable. For testing the ideas a Cockroft-Walton generator has been chosen.

High efficiency and CW operation can be obtained only if a good recovery of the spent e-beam is provided and only a fraction of 1% of the total electron charge stored in the beam is lost while transporting it throughout the system. The condition of low charge and energy loss can be achieved if a very high quality eb can be produced and maintained through the accelerator and transport system.

### The accelerator

Since the electron beam quality worsens after the interaction within the FEL, the guiding system from the gun to the collector must be very effective. Thus the transport channel is the most important section of the device.

In the first experiment at the University of California S. Barbara (UCSB) [3], L. Elias and coworkers have adopted a standard transport system. The losses along a transport channel several meters long with drift and bending sections, and focusing lenses, increase together with the transverse emittance and energy spread. In fact the aberration effect of the lenses and the imperfections of the bending magnet fields pile up along the line producing a deterioration of the beam quality that, of course, increases with the transport channel length. In addition, for high intensity electron beams, the space charge effect contribute to increase losses; because of this the CW operation becomes impossible.

A solution to this problem can be given by an "immersed flow" design of the whole layout. In fact in this method of beam focusing, that involves an immersion of the entire region of flow in a uniform axial magnetic field obtained by a solenoid winding, the electrons tend to follow the lines of magnetic flux. Since the magnetic field is normal to the cathode and uniform along the entire length of the tube, an inward Lorentz force, to counterbalance the space charge expansion force, can arise only as a result of radial displacement of electrons. Thus perturbations in the diameter of the stream is inherent in the method of immersed flow, and only the magnitude of the ripples is reduced by an increase in the magnetic flux density. In the regime operation the following small amplitude equation for the eb maximum radius normalized to the initial one [4]

$$R_{\max} = 1 + \frac{1}{(\omega_h/\omega_p)^2} + \frac{R'_0}{(\omega_h/\omega_p)} \quad (1)$$

can be deduced; here  $R'_0$  is the initial slope normalized to the initial radius, and  $\omega_h$ ,  $\omega_p$  are respectively the cyclotron and plasma frequency. Eq. (1) is valid for large values of the ratio  $(\omega_h/\omega_p)$ . Since this ratio grows linearly with the flux density, from eq. (1) is evident that this must be increased almost in direct proportion to the increase in initial slope in order to maintain a given amplitude of beam scallops. Thus a reduction in the value of  $R'_0$  in a given case can allow a substantial reduction in the magnetic field required to confine a given beam (flat cathode).

A high axial magnetic field prevents from the spatial dispersion of the eb in the collector because all the electrons are tightly bound to their magnetic flux lines, thus it has to be relatively low. Therefore some magnetic lenses must be added along the transport channel to the axial field. This latter should be enough to prevent any charge loss, while the former should reduce the beam size to a fraction of the square centimeter at the center of the FEL and at the entrance of the collector. The calculations show that the axial magnetic field ought to be around 100 Gauss. The beam scallop infers with FEL operation through the possible coupling between the betatron and wiggling motion of the electrons [5]. It is convenient to have  $\lambda_b > \lambda_w$ , that is the betatron wavelength greater than the wiggler one.

The accelerator for this experiment has already been designed for e-cooling job [6]. It is going to be assembled in the next months at the Legnaro (Padova) laboratory of the Istituto Nazionale di Fisica Nucleare (INFN). The electrostatic accelerator is of a Cockroft-Walton type with an energy of 700 KeV and a current of 3 A. The transport channel is full immersed in an axial magnetic flux density which also accomplish the bending operation together with the guiding of the electron beam. The design of the e-gun and of the electron collector is made in order to meet the requirements of the FEL operation.

To produce high current eb with low voltage we need to design an electron gun with a high perveance parameter.

<sup>+</sup> Dipartimento di Fisica e INFN-Sezione di Milano

<sup>++</sup> Dipartimento di Fisica e INFN-Sezione di Torino

Since in this kind of gun the space charge effect is consistent, we have to take it into account in our calculations. The geometrical design of the electron gun has been carried out with the aid of the computer code SLACGUN by W.B. Herrmannsfeldt [7]; the source is of Pierce type (see fig. 1) and it is designed to operate at a total electron current of 3 Ampères at 12 KV (extraction electrode). We have suitably modified the e-gun used in the e-cooling set-up. The new cathode have a radius of 8 mm instead of 15 mm. In order to maintain a current of 3 Ampères with a smaller cathode we had to increase the perveance (by closing the grid electrode to the cathode). To minimize the corresponding increase of transverse energy (space charge and diverging lens effect increasing) we chose properly the Pierce angle of the focusing electrode.

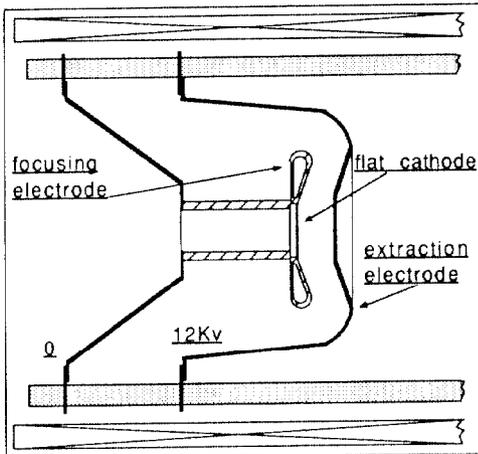


Fig. 1. Sketch of the modified gun for the e-cooling experiment.

#### The multistage collector

A powerful high voltage generator can provide a power of some hundreds of kilowatts, whereas the beam has the power of some megawatts. As it has been stressed above, an eb having such characteristics is possible only if its energy is continuously recovered after its interaction throughout the experimental set-up. Thus the crucial element of a multiampères electrostatic accelerator for FEL application becomes the collector for the beam recovery.

After interaction with radiation beam along the undulator the electron beam is energy spreaded with a FWHW [9]

$$\frac{\Delta\gamma}{\gamma} = \frac{1}{2N} \quad (2)$$

where  $N$  is the undulator periods.

In a possible FEL layout we assume  $N = 50$ , so the electron beam has an energy spread of 1%. In this case standard collectors (Faraday cups) are not efficient. To get enough efficiency a multistage collector must be used.

The principle of a multistage collector is to spatially disperse the electrons with different energies so that they can be collected, on the proper electrode, possibly at zero or very small energy. The most important characteristic of a multistage collector is its energy resolving power matched with the collecting structure. The desired dispersive property can be obtained with either an electrostatic or/and a magnetic field.

In the first multistage collector built at the UCSB Van de Graaf with beam recovery [10] the spatial separation is obtained by applying a purely electric axial field when

particles enter the collector with a small transverse velocity component. The electrons having different energies in the range 0 - 10 KeV make different parabolic paths thus impinging the electrode having the right voltage. Therefore the dispersion is obtained simply by tilting the axis of the collector with respect to the beam propagation direction. The UCSB collector has three stages separated by 3.3 KV one from the other. From that value we may assess that with an ideal electron beam the collector losses are around 15%. The measured collector losses resulted in 25%[11].

We have studied and simulated a different collector design: the dispersive property are obtained by adding both a transverse magnetic field to the decelerating axial electric field and a transverse electric field [12]. This latter is obtained by tilting the collector electrodes. In this collector the particles follow more straight paths till they loose almost completely their longitudinal kinetic energy resulting in a stronger beam spatial dispersion which allows a higher collecting stages number.

This kind of multistage collector cannot be used in our first experiment owing to the "immersed flow" configuration. As said before, it is compulsory to set the collector out of the solenoid in order to reduce the axial magnetic field acting on the electron beam (fig. 2), so that the transverse electric field can pull away the electrons. These have helical paths whose centers follow parabolic trajectories dependent on the electron initial velocity [13].

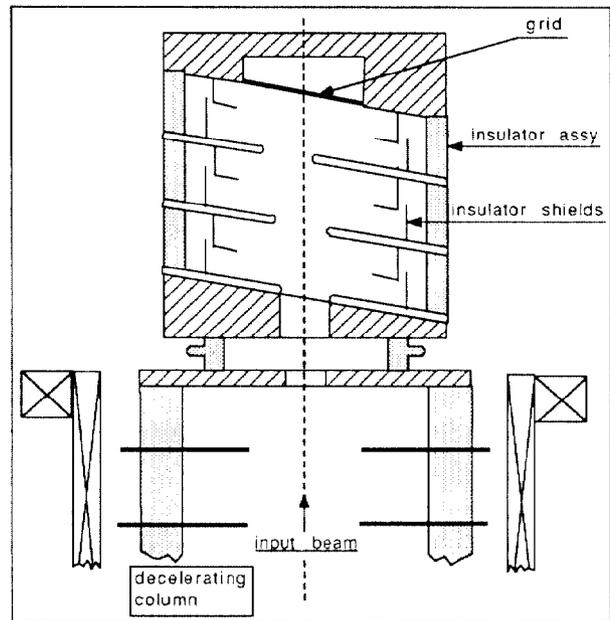


Fig. 2. Sketch of the collector: the center of the plates is shifting as the axis of the electron beam; the focusing lens shrinks the beam size at the collector entrance.

In this collector the recovery efficiency is not as good as in collector of ref. [12], however it can be assessed around 50%. We point that the design of the electrodes must be finely calculated. The obtained results allow some final comments

- the charge recovery is foreseen to be very good, maybe better than 99%
- the collector, even with an axial magnetic field, has a recovery efficiency allowing CW operation
- the collector axis is not tilted with respect to the accelerating column, thus it can have many collecting plates.

The transverse beam energy and dimensions along the entire transport from the gun to the collector for the

Legnaro set-up modified for FEL experiment, have been calculated by SLACGUN. In fig. 3 are reported the computer results for the modified sections of the set-up.

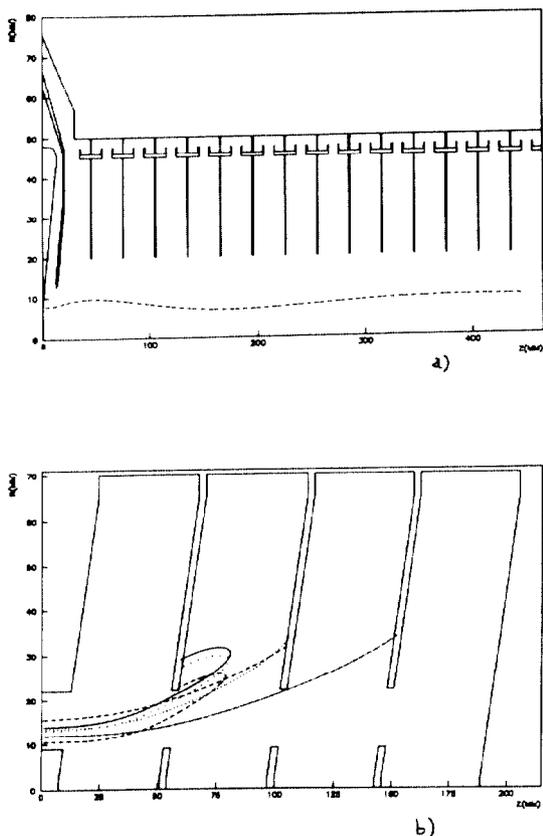


Fig. 3. a) extreme ray of the eb in the gun region and in the first part of the accelerating column; b) some computed electron trajectories in the multistage collector.

### Conclusions

A high power CW full immersed electrostatic accelerator with a multistage collector for the recovery of an electron beam with an energy spread of 1% seems feasible. An estimate efficiency of the energy recovery is about 50% and the charge recovery can be as high as 99% owing to the "immersed flow" configuration of the electron beam transport channel.

### References

- [1] G. Dattoli and A. Renieri, "Experimental and theoretical aspects of the Free Electron Laser," in Laser Handbook, vol. 4, eds. M.L. Stich and M.S. Bass, Amsterdam: North Holland, 1985.
- [2] I. Boscolo, V. Stagno and V. Variale, "A Small Electrostatic Accelerator for a Powerful CW FEL," (to appear on Nucl. Instrum. and Meth.)
- [3] L. R. Elias, G. Ramian, "Status Report on the S. Barbara FEL Experiment", in: Free Electron Generators of Coherent Radiation, ed. C.A. Brau et al., vol. 453, p. 137, 1983.

- [4] G.R. Brewer, "High-Intensity Electron Guns", in Focusing of Charged Particles, ed. A. Septier, New York: Academic Press, 1967, vol. II, p. 87.
- [5] E.T. Scharlemann, "Wiggle plane focusing in linear wigglers," Journal of Appl. Phys., vol. 58, pp. 2154-2161, September 1985.
- [6] L. Busso et. al., "An electron cooling device in the one MeV energy region", in: Proceedings of the XIII International Conference on High Energy Accelerators, 1986, pp. 344-347.
- [7] W.B. Herrmannsfeldt, "Electron Trajectory Program", SLAC-Report 226, 1979.
- [8] U. Bizzarri et al, "Electron Cooling Device at 500 KeV with a Cockroft-Walton Generator", INFN-Report, LNF-81/30(R), 1981.
- [9] see for ex.: "Novel Sources of Coherent Radiation", ed. S.F. Jacobs et. al., Addison-Wesley, Reading MA, 1978.
- [10] L. R. Elias, G. Ramian, "Design of the UCSB FEL Electron Beam System, in: Free -Electron Generators of Coherent Radiation, eds. S.F. Jacobs et al., vol.9, New-York: Addison-Wesley, 1982, p. 577-601.
- [11] Private communication by L. Elias.
- [12] I. Boscolo, G. Brautti, V. Stagno and V. Variale, "A High Efficiency Collector for a Low Quality Electron Beam Recovery", (to appear on Nucl. Instrum. and Meth.)
- [13] J.D. Jackson, Classical Electrodynamics. New York: John Wiley & Sons, ch. 12, pp. 571-593.