# PRODUCTION AND DYNAMICS OF HIGH INTENSITY ELECTRON BEAMS +

G.Brautti - Istituto di Fisica dell'Università - Bari - Italy
I.Boscolo, R.Coisson, M.Leo, A.Luches, A.Tepore - Istituto di Fisica dell'Università - Lecce - Italy

## SUMMARY

High intensity electron beam experiments are in progress at electron energies varying from 100 keV to 2 MeV. The low energy machines are Marx generators, while the high energy one is an electron beam transformer accelerator, home made with some original technical solutions. Its electron energy is 2 MeV, current > 10 kA, pulse length 20 ns at a repetition rate of 10 pps. The purpose is injection in the ANEL - type electron ring accelerators, beam dynamics and plasma - beam interaction investigations. Several models of field emission diodes have been investigated by various diagnostic methods and beam pictures on various materials have been taken.

## INTRODUCTION

Since about ten years there is an ever increasing interest about high intensity pulsed electron beams. They are utilized mainly for plasma - beam interaction studies, while from 1970[1] many efforts are made to produce and accelerate ions by collective effects to energies higher than that of the electrons. The collective field effects are enhanced in the ERA experiments, where the electron beam is shaped in annular form.

In our laboratories works are in progress both in the field of production and acceleration of ions by intense linear electron beams and in the field of electron ring accelerators.

The high voltage pulsers now in use are two Marx generators whose parameters are summarized in Table 1, while a transformer accelerator is in advanced stage of assembly.

Table 1

| | Marx 1 | Marx 2 |
|---|---|---|
| Charging Voltage | 25kV | 20kV |
| Number of Stages | 8 | 20 |
| Output Voltage | 200kV | 400kV |
| Stage Capacitance | 2000pF | .027μF |

The pulsers feed field emission diodes via pulse forming lines. Many field emission diodes were made and are in operation for beam dynamics investigations. The electron beams (more than $10^{13}$ electrons/pulse) are allowed to drift in a tube filled with gas at variable pressure and search for produced ions will start next months. However the main purpose of the apparatus is to give short high intensity electron beams to inject in the ANEL - type electron ring accelerators.

We remind briefly the Transverse - ERA principle on which the ANEL machines are based

An electron beam is injected in a magnetic field of shape

$$B_z = B_o(1 - ky - s^2y^2)$$

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An electron ring of average radius

$$r_{avg} = p/B_{avg}$$

is formed and, if we make k≠0, the ring drifts perpendicularly to the magnetic field if certain stability conditions are satisfied.

Ions are formed by electron impact and are accelerated by the electric field produced by the drifting ring. The attainable electric fields, the space charge limits and the ring life have been computed for various electron energies and reported elsewhere.[2]

## ELECTRON INJECTION IN ANEL 1

The first injection tests were made in the ANEL 1 with a small field emission diode operated directly inside the magnet.[3] The little space available limited the operation to the range 100 - 200 keV. An external diode is now built, with the injector optics shown in fig. 1. A magnetic septum will be used to fill efficiently the transverse phase space. As an alternative to the rather conventional septum now being built, we are considering a self - excited septum. It consists essentially in a conductive pipe, on one side of which both image current and charges are developed, while on the opposite side the appearance of the image currents is prevented by a series of slots perpendicular to the tube axis. This system develops a net deflecting force proportional to the beam current.

## NEW INJECTOR DEVELOPMENT

A new electron injector of higher energy is now almost ready for operation. It will allow our ANEL machines to come out of the modelling age to obtain interesting collective fields (fig.2).

The injector will have two different accelerating stages (fig.3). The first stage is of the Tesla transformer type, home made with some original technical solutions. Its electron energy is 2 MeV, current > 10 kA, pulse length 20 ns and repetition rate of 10 pps.

The short coaxial line (l=1 m) which forms the HV capacitor (∿ 200 pF) is not suited to deliver well shaped pulses to a matched load, but it is rather intended to give a current pulse of moderate intensity with an exponential decrease of current and voltage (fig.4). Provision is made for triggering the HV spark gap by a fast UV light pulse from a nitrogen laser, which allows a precise synchronization with the following stage.

The electron source is a short cold emission diode of rather conventional design.

After the first stage an energy selector will be provided. It will select an energy band of adjustable width, with a fast rise and fall of the beam current.

As an alternative option we plan to replace the field emission cathode by a photo - electric cathode operated by a nitrogen laser pulse. Since this provides a good definition of both the energy and duration of the beam, we shall be dispensed in this case with both the HV spark gap and the energy selector.

The second stage is a Linear Induction Accelerator with ferrite cores. It is of rather simple modular design, with focusing obtained by short solenoid lenses which can be inserted between any pair of Linear Induction modules. A few Linear Induction and lens modules were built and are now under test. A special pulse - forming network will be used to produce a trapezoidal voltage shape. This will be used to produce the energy modulation required for the klystron bunching of the electron ring.

The planned energy increase given by the Linear Induction Accelerator is of the order of 1 MeV, for currents of a few kA.

## COMPRESSION BY KLYSTRON BUNCHING

As explained in [2], the only compression mechanism which we plan to use in the ANEL 1, static field device, can be described as "klystron bunching".

The drift speed of the ring is related to the magnetic field gradient k, to the major radius $r_o$ of the ring and to the electron speed by the approximate formula

$$v_d = k r_o v_e / 2$$

Even if the variation of the $v_e$ factor can be neglected for relativistic electrons, the drift speed can be strongly modulated by changing $r_o$ through the electron momentum. We are designing the injection system to produce the bunching at $x_o$=30cm after injection, for a drift speed of about $10^7$m/s. The required rate of change of the (relativistic) electron energy is given by the formula

$$d(\ln E)/dt = v_d/l$$

The approximate ring spread δ versus length is indicated in fig.5, with the corresponding maximum field available for heavy ion acceleration.

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References
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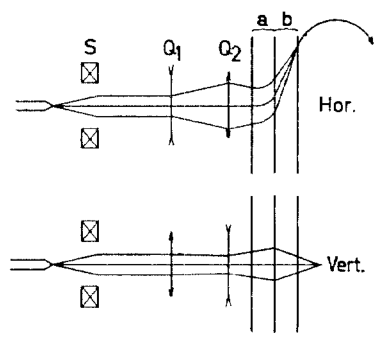


Fig.1 - Injector optics - S) Solenoid; $Q_1, Q_2$) quadrupoles; a)region of overcompensated field; b)region of compensated field.

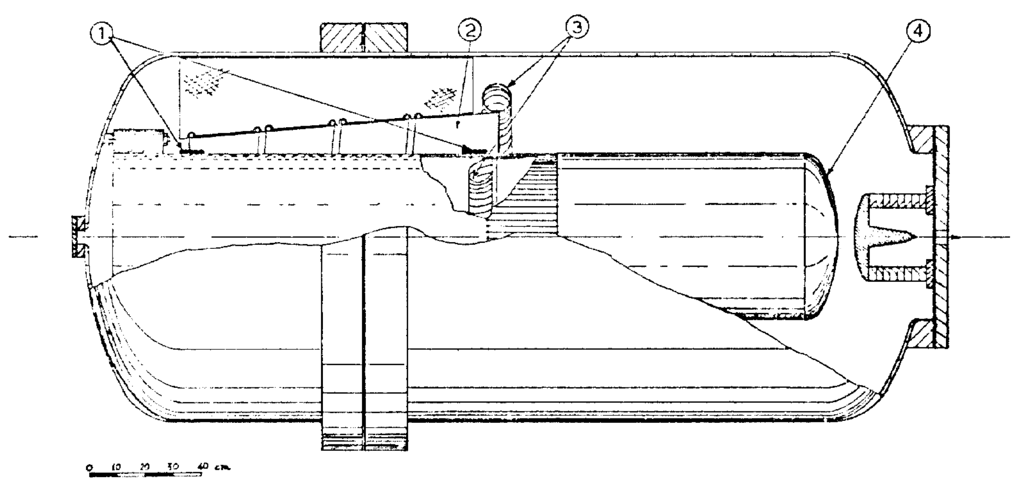


Fig.2 - Tesla transformer - 1)Secondary windings; 2)primary windings; 3)guard rings 4)HV terminal.

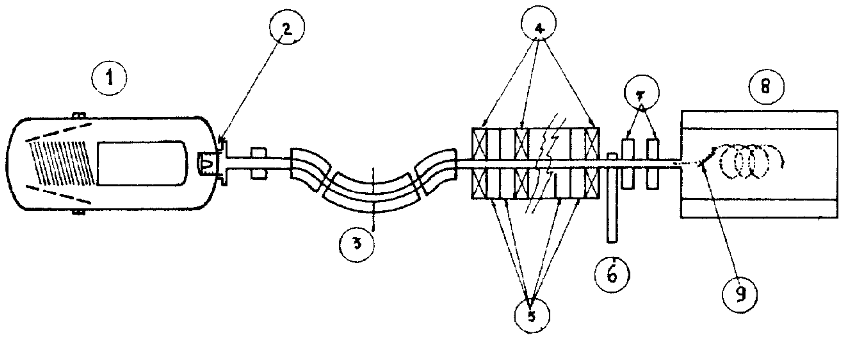


Fig.3 - Complete system - 1)Tesla transformer; 2)diode; 3)energy selector; 4)focusing coils; 5)linear induction modules; 6) beam monitor; 7)focusing and matching quadrupoles;8)ANEL 1 magnet; 9)injection septum.

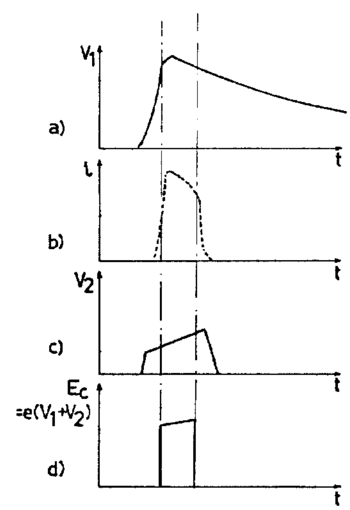


Fig.4 - Current and voltage patterns - a)diode voltage; b)current after energy selector c)linear induction accelerator voltage; d)beam energy.

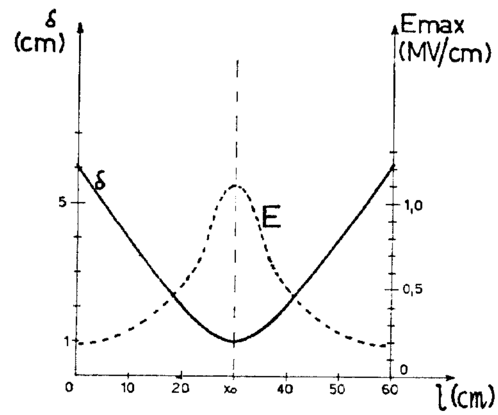


Fig.5 - Ring spread and maximum field versus drift length.