HIGH-QUALITY ELECTRON BEAM WITH NON ADIABATIC PUMPING

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In this paper we report on numerical simulation and experimental test of a non-adiabatic gun which generates a high-quality annular electron beam by an electrostatic pumping method. The experimental gun geometry produces a 500 kV, 700 A electron beam with total power about 250 MW in 30 ns pulse length. Measured beam parameters are compared to numerical calculations that predict an electron velocity pitch ratio of 0.6, perpendicular and longitudinal velocity spreads of 1.5% and 0.1%, respectively, after adiabatic magnetic compression.

A critical element of FELs and CARMs devices is the electro-optical system, which must generate a high-quality electron beam with sharply defined partition of energy between rotation and streaming energy along the axial guide magnetic field. There are two main schemes for generating helical electron beams. The first method employs a magnetron injection gun, a crossed-field emitter consisting of a conical shaped cathode surrounded by a control electrode where the beam is created with an initial oscillatory velocity. The other scheme is the so-called non-adiabatic gun. In this scheme, a rectilinear flowing beam is generated first and then is passed through a non-adiabatic modulation region where the electrons are set to rotating. The non-adiabatic modulation can be performed either by using magnetic or electric fields, and the required final transverse electron momentum in the resonant cavity is obtained by adiabatically compressing the beam as it leaves the gun region.

In the present paper, we propose a novel configuration of a high voltage non-adiabatic gun producing a high-quality, several amperes electron beam. Fig. 1 illustrates the experimental geometry. A double-coaxial pulse line accelerator PERUN-2 generates a 500 kV pulse with duration of 30 ns. The cathode is a hollow cylinder with external and internal diameters of 6.4 cm and 3.1 cm, respectively. The annular electron beam is generated by explosive plasma formation from a graphite ringlike emitter fitted on a well polished surface. The emitter ring has a diameter of 4.5 cm and width of 1.5 mm. A stepped iris anode placed away 3.0 cm from the cathode provides electric field modulation and beam control. Such a configuration is used for the following two reasons. Firstly, the cathode end-face area should be large enough to keep the electric field distribution quite homogeneous over the region close to the emitter. Secondly, the emitter is positioned far from the side-on cathode surface to eliminate any strong edge-current emission. Downstream the iris, the beam propagates through a 6.2 cm-diameter drift tube immersed in a homogeneous axial magnetic field.

The above described gun geometry was optimized using the ray-tracing SLAC program [1]. Fig. 2 shows the parallel and perpendicular velocities along the axial distance for a 700 A beam current. The axial scale for this and the next plots is calibrated in mesh unities, where 1 m.u=3 mm. As can be seen in Fig. 2, the transverse electron velocity is induced by transit through the localized increasing in the radial electric field, which is produced by the stepped iris anode. Since the axial velocity is nearly constant along the pumping region where the transverse velocity keeps rising, this leads to an increase in the pitch ratio as shown in Fig. 3. The electron trajectory code indicates that the radial electric field experienced by the outer and inner most electrons are on the order of 17 kV/cm and 7.5 kV/cm, respectively, which gives a transverse velocity spread as high as 17% in the beam extraction region (Fig. 4). Downstream, however, the radial electric field E_r distribution becomes more uniform and the transverse velocity spread drops down to 1%. In contrast to E_r, the axial electric field E_z near the emitting surface is much stronger ($\sim 200 kV/\text{cm}$) and nearly uniform, thus yielding a very small axial velocity spread as displayed in Fig. 5.

The electron gun has been tested using special diode condition including a diode mismatching in order to obtain the desired voltage tuning. We have used a few diagnostics on our beam line that allows us to determine the full diode and actual beam current, diode voltage, beam position and pitch ratio α. The full current has been measured by a Rogowsky coil mounted in the end of the coaxial line. Just close to the diode a voltage monitor has been installed. These probes gave us information about full diode current, voltage and pulse shape. The actual beam current has been measured by a Faraday cup, which is assembled from graphite cylinder, collecting the beam electrons and directing the resulting current through a low resistence to the ground. The other diagnostic is a diamagnetic loop, placed in a plane of constant axial position encircling the beam path. Both anode and cathode were immersed in a honogeneous magnetic field, produced by a solenoidal magnet with pulse duration of $\sim 12\,\text{ms}$.

In our experiment we used two emitter rings. The first one bulging out from the supporting metallic surface by 0.2 mm while the second one has a 0.3 mm bulge. The rings have been fabricated with rounded corners. The reason to use this kind of emitter is that when the emitting surface coincides with the surface supporter, the extracted current is unfavourably low. In this case, moreover, we observed emission from the corners where the ring is placed.

The beam-trace pictures have been taken along the z-axis with a 1 cm step interval. Using these photographs we compared the beam profile and thickness with computer simulations. Measurements showed that for the ring with the bulge of 0.2 mm the beam properties are almost identical to those predicted by numerical simulation, especially when the outer corner is well rounded. This scanning has been done for magnetic field varying between 2.0 and 2.5 kG. Difficulties arose from measuring the pitch ratio, because its value is small. It is interesting to note that all values of α derived from the diamagnetic loop's signal were over 1.5 times larger than those the SLAC code predicts. In addition, discrepancy is larger when the current is higher. The beam current was varied in a wide range between 350 and 600 A. For the above current interval the voltage pulse decreased from 550 to 500 kV. The best fitness of the measured beam parameters (α and electron flow thickeness in the plane perpendicular to z-axis) with the computational predictions were obtained at a magnetic field of 2.3 kG and $I_b \sim 400\,\text{A}$.

In conclusion, we described in this paper experimental test and simulations of a nonadiabatic relativistic electron gun which is able to generate a flow with appropriate properties and low velocity spread. The computational predictions and experimental test are in a good agreement. There is a difference between the measured and calculated values of α, which could be attributed to voltage fluctuations, errors in the calculation of pitch ratio from the diamagnetic loop signal and diode misalignment.

Reference:

[1] W.B. Herrmannsfeldt, "Electron Trajectory Program", Stanford Univ., SLAC Report 226, Nov. 1979.

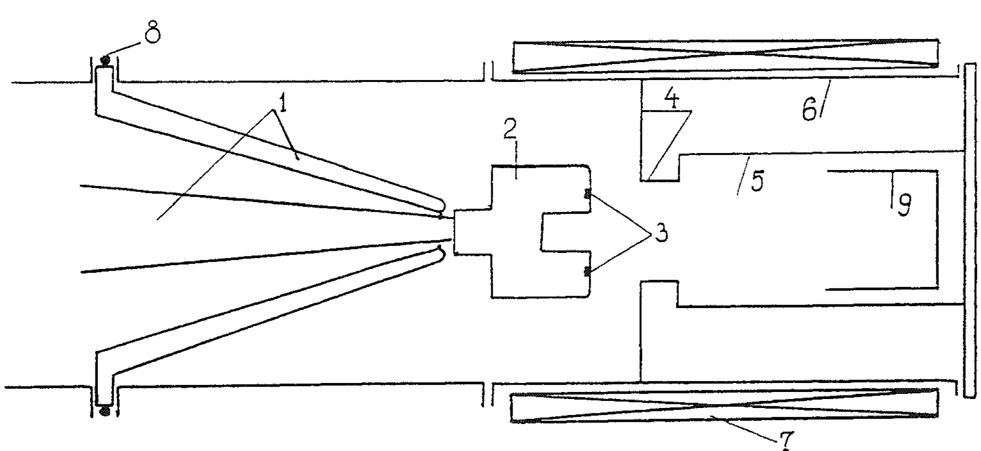

Fig. 1 Experimental setup: 1. Matching cone; 2. Anode; 3. Emitter ring; 4. Stepped iris cathode; 5. Drift tube; 6. Vacuum chamber; 7. Solenoidal magnet; 8. Rogowsky coil; 9. Collector.

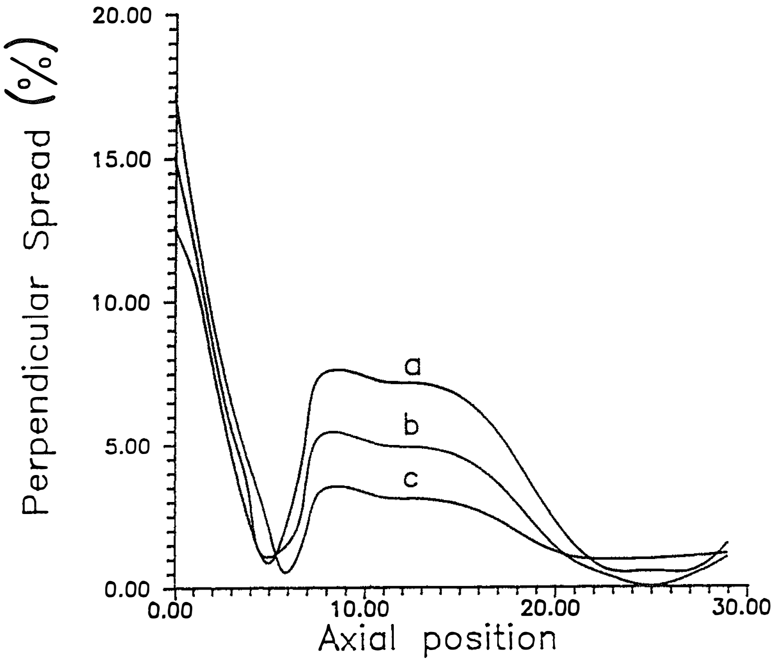

Fig. 4 Perpendicular velocity spread as function of axial position for different beam currents: (a) 300 A; (b) 500 A; (c) 700 A.

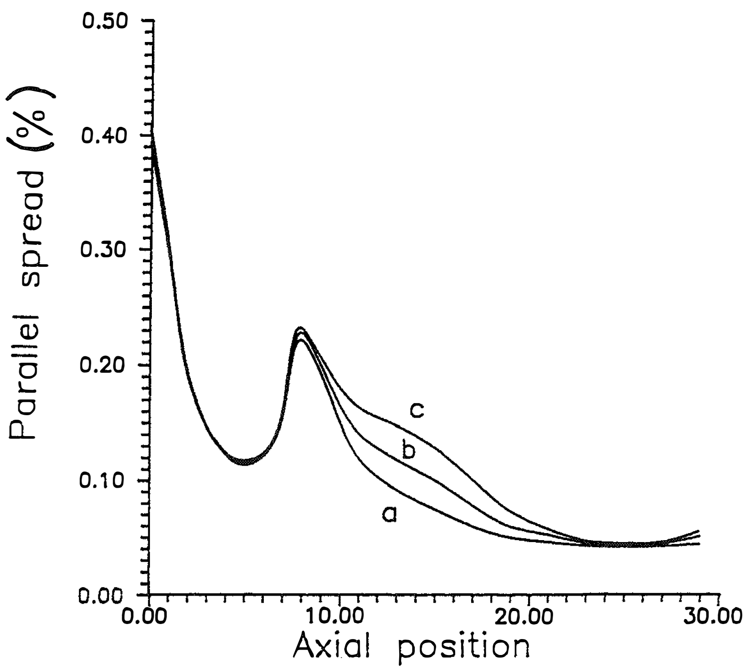

Fig. 5 Parallel velocity spread as a function of axial position for different beam currents: (a) 300 A; (b) 500 A; (c) 700 A.

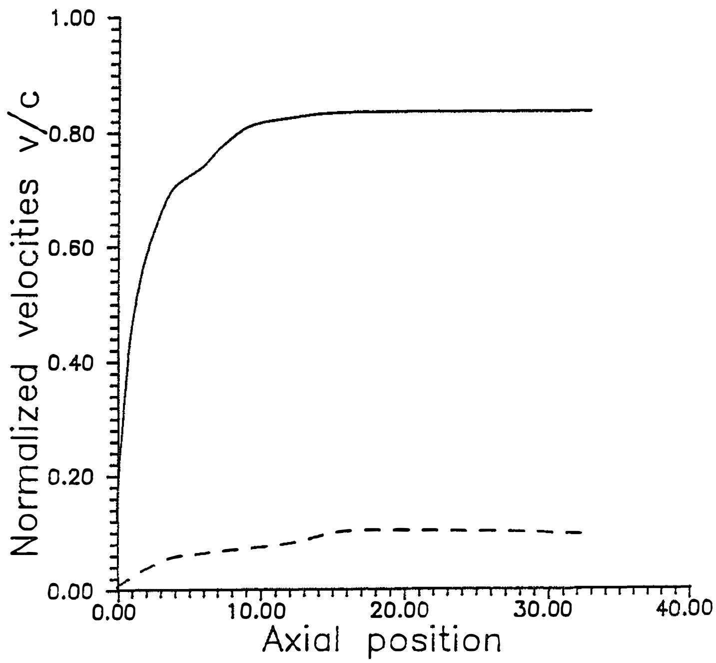

Fig. 2 Normalized axial (solid line) and perpendicular (dashed line) velocities as funcion of axial position.

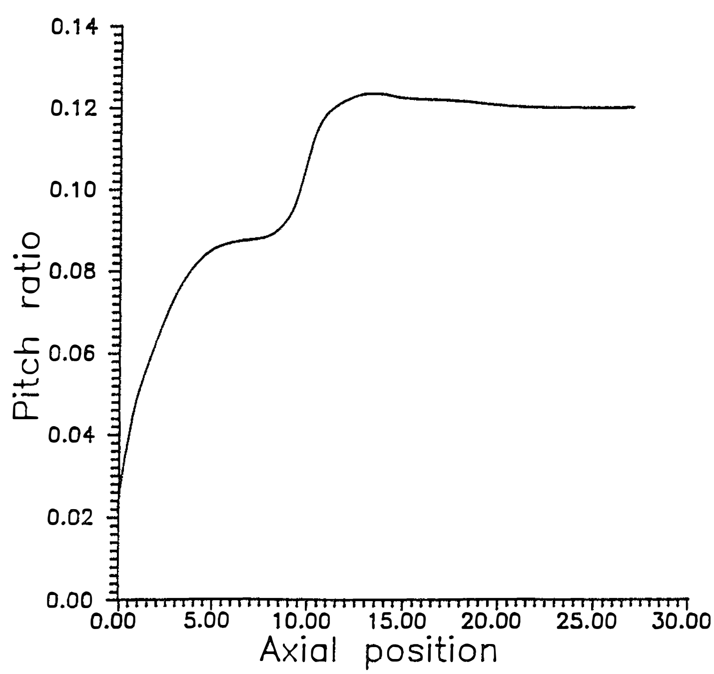

Fig. 3 Pitch ratio α as a function of axial position.