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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

ELSEVIER

Velocity distributions produced by a thermionic electron gun and the effect on the performance of a Cherenkov FEL

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1. Electron beam velocity distributions

For a normal thermionic electron gun, with a limited current density of the order of $10 A/cm^2$ at the cathode surface, (magnetic) beam compression is required to obtain an electron beam current with a larger density. This method is used in an electron gun for a Cherenkov FEL with an annular emmiting surface [1,2]. When the electron beam is compressed from its initial dimensions at the cathode to its final dimensions in the interaction region of the CFEL, the electrons obtain a small transverse momentum and perform a Larmor motion around a centre given by the magnetic field lines. The amount of transverse momentum obtained depends on the geometry of the magnetic field and the value of the field at the cathode B_c. The total compression is given by $r_b/r_c = \sqrt{B_c/B_0}$, where r_b is the final beam radius, B_0 is the field in the homogenous interaction region and r_c is the maximum radius of the emitting surface at the cathode. By varying the position or current through one of the coils producing the field, it becomes possible for electrons to have zero transverse velocity when they are emitted from a particular radius r_z at the cathode or, correspondingly, for a particular radius within the final electron beam. However, it is not possible to have zero transverse velocity over the complete beam cross section since it is not possible to vary the magnetic field over the beam dimensions. Fig. 1 shows the electrode configuration of the gun together with the inner, centre and outer electron trajectory and the longitudinal and transverse velocity corresponding to those trajectories. The insertion shows the beam trajectories somewhere in the interaction region. The magnetic field is configured for a matched trajectory at the centre. Numerical simulations of single particle trajectories in the given electrostatic accelerating and magnetostatic compression fields of the gun show that the transverse momentum in the interaction region is nearly linear with the displacement from r_z: $p_\perp/\gamma mc = k_p(r_i - r_z)$, where r_i is the radial position of the emitted electron and k_p is a constant almost independent of the magnetic field when it is optimised for a specific value of r_z. One easily finds that the longitudinal velocity distribution as a function of radial position is approximately parabolic of shape and that the maximum is determined by the position of r_z.

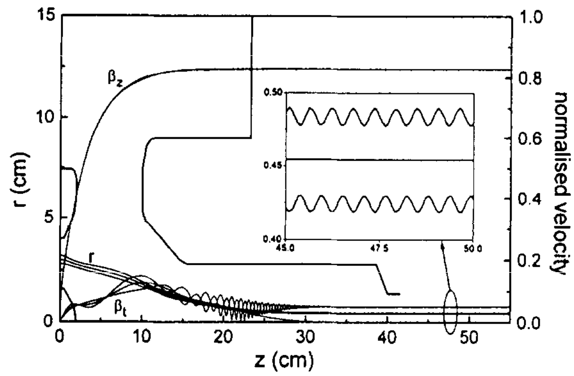

Fig. 1. Electrode configuration and electron trajectories.

2. Performance of the Cherenkov FEL

In order to investigate the influence of these type of velocity distributions, in particular the dependence on r_z, a non-linear model of the CFEL [3] was adjusted to have initial velocities of the electrons by using a random angle distributions to calculate the two transverse components from $p_\perp$ for a particle emitted at radial position r_i and conservation of energy was used to calculate the longitudinal component. Compared to the real electron trajectories, this effectively changes the centre of the Larmor motion of the electrons and the outer beam radius will be larger by about the Larmor radius. Fig. 2 shows the average longitudinal velocity and spread as a function of r_z for a typical value of k_p. A typical result for the laser is

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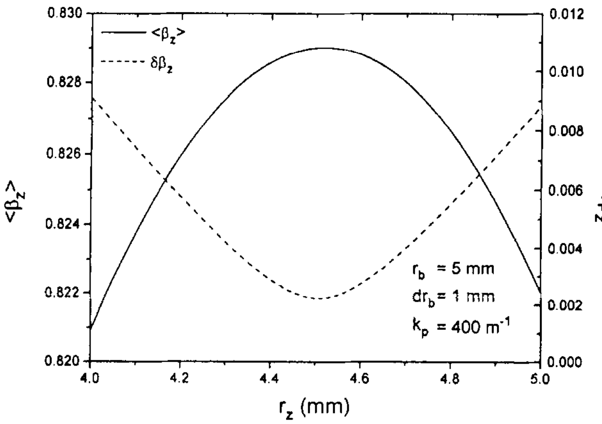

Fig. 2. Average velocity and spread as a function of r_z.

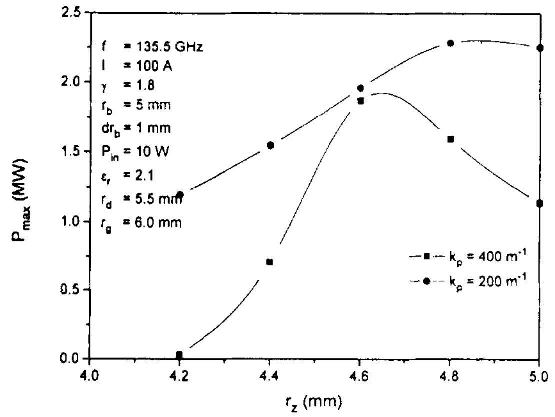

Fig. 3. Maximum power as a function of r_z.

shown in Fig. 3 where the maximum power is plotted as a function of r_z for two values of k_p. An increase in k_p has several effects. First a stronger dependence on r_z is found. This is due to an increased variation of the average longitudinal velocity with r_z for larger k_p and the fact that the frequency was kept fixed during the runs. Second the optimal value of r_z shifts towards the centre of the beam. This has to be attributed to the radial dependence of the electric field component of the amplified TM_{01} mode which falls of exponentially with the distance towards the dielectric liner. For equal spreads one expect an increased gain for r_z approaching the outer beam radius. However a change in r_z is accompanied by a change in the velocity spread which will counteract the increase in gain. Fig. 3 shows the results of these combined effect.

References

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