FORMING OF PRECISION THIN-WALL HOLLOW ELECTRON BEAMS FOR MICROWAVE GENERATORS

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INTRODUCTION

Effective operation of a short-wave-length Cherenkov-type free-electron laser implies employment of a high-quality intense electron beam with small spread in longitudinal momentum and beam-wall separation comparable with the radiation wave-length times Lorentz-factor of the electrons. A specialized e-gun to produce a high brightness beam for sub-millimeter FEL application has been designed and constructed with parameters indicated in Table 1, [1, 2].

A plane, ring-shaped, thermionic lanthanum hexaboride cathode, having a 28-mm average radius and a 6–8 mm width, is used to produce an annular beam. The cathode surface is screened by two focusing electrodes to operate in a space charge limited regime. Uniformity of temperature distribution across the ring-shaped cathode is provided by a machined-graphite heater. Its current is fed in bifilar geometry. The focusing system must form a laminar beam inside the accelerating gap at rather low magnetic field and transport the beam to an experimental region of about 50 cm length with large magnetic field of about 15 kG.

Table 1

Voltage, V	300 – 500 kV
Beam current, I	> 100 A
Repetition rate, f	Up to 10 Hz
Beam mean diameter inside the interaction region, d	5 mm
Beam mean diameter at the cathode, D	56 mm
Beam thickness inside the interaction region, Δ	< 1 mm
Longitudinal momentum spread, $\Delta p_z / p_z$	<1%

BUMP-SCHEME OF BEAM FORMATION AND COMPUTER SIMULATION OF BEAM DYNAMICS

To preserve the low beam emittance under the strong non-adiabatic compression and under possible variations of beam energy, the main dynamics was calculated using three codes.

A single particle code TRACE providing high-precision trajectory calculations was used to optimize the magnetic field profile with respect to the longitudinal momentum spread of electrons emitted from different points of the cathode. The main calculations of the beam self-consistent dynamics were carried out with electromagnetic PIC-code KARAT [3]. The steady-state code SAM [4] was used to verify integral characteristics of the beam.

The last two codes gave approximately the same integral characteristics of the beam but different structures of the flow especially in the region near the cathode surface. In particular, in a transient regime some hysteresis effects were observed [5].

The results of computations listed below are relevant to the gap region. An additional compression with a separate matched solenoid will be provided at the FEL entrance.

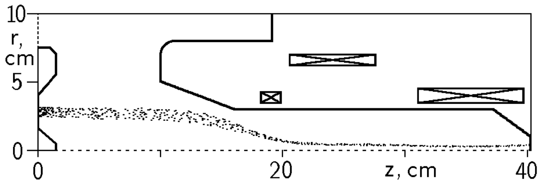

Fig 1: A simplified electrode configuration with magnetic coils and corresponding beam profile. The calculated microperveance was 0.525 $\mu A/V^{3/2}$

A simplified electrode configuration with magnetic coils and corresponding beam behavior are presented in Fig.1. The required magnetic field formed by three coils is also shown in Fig.2.

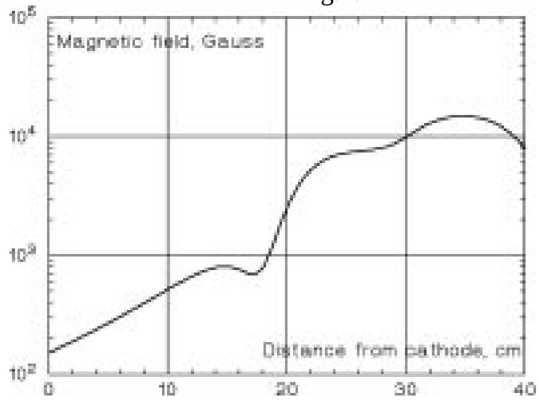

Fig 2: The required magnetic field formed by three coils

The third coil produces the main magnetic field. It is used for investigation of beam dynamics and its parameters at the output of the gun. It has to be changed for a long matched solenoid for experimental investigation of FEL. The second coil and the first one are correcting and focusing elements simultaneously. The distance between them and currents in the coils are parameters, which used to “seat” electrons on the right magnetic force line. The first coil provides an opposite magnetic flux to create a correcting bump in the magnetic field profile. The second coil provides the sharp rise of the magnetic field at the background of the field created by third coil.

The longitudinal momentum spread was found to be rather sensitive with respect to coil position and currents: ± 1 mm displacement of one of the first two coils led to a significant increase in the spread and in the beam wall thickness. About the same effect was induced by ± 1% current variations in the coils. The effect of common displacements of the coils or common variations of the currents was weaker. The position of the 3-d coil and its current variations are not so crucial. It should be noted that the crossover formed close to the cathode under action of the focusing electrodes in single-particle calculations disappears as a result of beam space charge, which in this case favorably affects beam quality.

Fig.3a shows the trajectories of three individual particles emitted, respectively, from the cathode central, inner and outer radius of the annular cathode, and the magnetic field line of force passing through the emitting point at the central radius. Fig.3b shows the behavior of the longitudinal and transversal momenta of these three electrons.

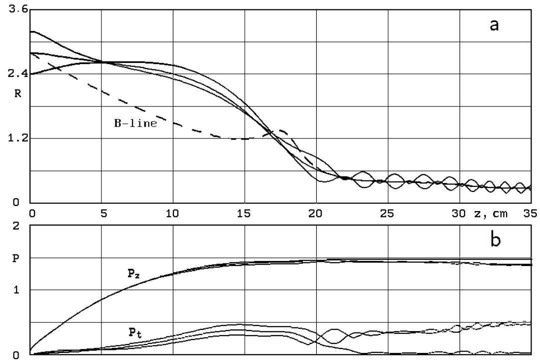

Fig 3: The trajectories of three test particles, emitted from central, inner and outer radius of the annular cathode (a) and the behavior of longitudinal and transversal momenta (b).

The trajectory of the electron emitted from central part of the cathode follows along magnetic field line in the region of large magnetic field and crosses field lines inside the gap (Fig. 3a). The jump of the electron finishes smoothly at the slope of the field line with transversal momentum close to zero (Fig. 3b). Varying the bump of the field and the position of the first coil the same thing can be done with electrons emitted from inner or outer radius of the cathode.

An interesting feature of the chosen scheme is the scaling of coil exciting currents when changing accelerating voltage. For a fixed anode-cathode separation and variation of voltage from 200 to 500 kV, the beam structure remains practically unchanged if the coil currents are varied proportionally to the total momentum of particles corresponding to the applied voltage. This feature can turn out to be useful in creating an overall control system.

THE EXPERIMENTAL GUN

The scheme of the experimental gun is shown in Fig.4. The insulator of the gun consists of two parts: a conical ceramic (situll) part and a base Plexiglas diaphragm. A cathode cap with a water-cooled power supply junction is located at the top of the cone. The Plexiglas diaphragm is specially profiled to distribute the electric field uniformly. The 1:3 voltage ratio on the two parts of the insulator is produced by a resistive divider.

The cathode block includes a ring-shaped thermo emitter, central and peripheral focussing electrodes, a heater and heat screens. The changeable thermoemitter was formed by LaB_6 deposition on a thin molybdenum ring-shaped electrode. The inner and outer diameters of the emitting layer are 48 and 64 mm, respectively.

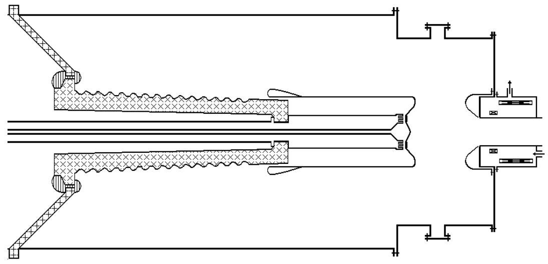

Fig. 4: The scheme of the electron gun.

The heater is made from a solid graphite block with machined non-conducting slots of bifilar geometry to decrease magnetic field perturbations at the cathode.

The vacuum vessel and the anode block are additionally cooled by water circulating through special channels within flanges and chamber walls.

The emission current of over 100 A is reached for 1.7 kW consumed power (20 V, 90 A).

Gun tests are carried out in a single-pulse regime on a special test facility based on a 10-stage open-air generator. For pulse shaping each stage is formed by a 6-cell artificial line. The facility includes a dividing transformer for the heater power supply, an oil tank for high voltage and heater current inputs, and a vacuum system.

The gun is positioned vertically on the oil tank. The maximum test voltage of 200 kV with a pulse flat top of 10-μs duration is limited by the dividing transformer of the cathode heater. The electron beam parameters measured in the test are close to theoretical calculations for the experiments. The thickness of the hollow beam measured at distance of 30 cm is less than 1 mm. This value indicates about the small longitudinal and transverse momentum spread.

CONCLUSION

The electron gun producing the precision hollow relativistic electron beam for coherent microwave generator applications has been developed and tested. It is based on the large non-adiabatic compression of the beam emitted by ring-shaped cathode with an active surface big enough to produce a wanted current level. Further improvement of beam quality is possible by decreasing of the width of the annular emitter and increasing its emissive power.

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