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VIRTUAL CATHODE DRIVEN BY SHORT PULSE ELECTRON GUN

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I. INTRODUCTION

In the past few years several laboratories and research centres concentrated their efforts in development and construction of new low cost, high repetition and flexible electron guns for applications in medicine, material treatment, spectroscopy, radars etc. Such machine has been already designed and constructed at ENEA (Italy) to power a free-electron laser (FEL) operating in the far infrared region. However, it can be used successfully to drive various microwave sources. In this paper numerical simulations, that have been performed for the future foil-diode vircator experiment, carried out at the ENEA gun are reported.

II. ELECTRON GUN DESIGN

A schematic diagram of the machine is shown in Fig. 1. The compactness required for the accelerator has brought the constructors to develop a pulser operating at high repetition rate with very short pulse duration. As can be seen from the principal scheme the electron gun is simply composed of five main components. Firstly, a 20 kV power supply charges a capacitor bank C_0 up to 20 kV, which plays a role of a primary energy storage reservoir. Next, discharge by the tyratron generates a 1μs long pulse. the transformers. Afterward six stages magnetic pulse compressor (PCS) reduces the pulse down to 30 ns and rises the voltage up to 350 kV at the final condenser of the compressor (the double pulse forming line - PFL) with energy transfer efficiency of about 70%. The line is filled with distilled water in order to minimise the size of the system. Its length is calculated so that it forms a 3ns output pulse. Since the gun is designed to drive a FEL the pulse is transformed additionally using a transmission line transformer (TLT). It consists of three coaxial 80 Ohms cables charged in parallel from the Blumline side and discharged in series on the diode load. If the diode is mismatched the voltage pulse could raise up to 1.8 MV. In our simulations we used a reduced scheme without TLT, i.e. the selftrigerinig line powers directly the diode. This gives the possibility of getting higher beam current at lower voltages. The short pulse duration is interesting because it gives rights to decrease considerably anode-cathode gap avoiding eventual gap closure. Moreover, it has been experimentally demonstrated that for few nanosecond pulse a gradient of 900 MV/m can be held [1].

III. SIMULATIONS WITH AN ANODE FOIL MODEL

It is the purpose of this paper to report a numerical investigation concerned with the optimal values of the solid cathode radius and pulse flat top duration with respect to the microwave radiation power and beam-to-microwave energy conversion efficiency for the future vircator experiment driven by short pulse machine.

An outline of the modelled axisymmetric system is shown in Fig. 2. The electron beam is formed in a foil diode with a 44-mm-radius anode tube. The electrons are generated by an explosive plasma emission from a solid cathode. A guiding magnetic field is not used. Beyond the anode foil positioned at a distance of d = 6 mm from the cathode front surface, the electrons propagate in an output drift tube (output waveguide) with a radius of R_w = 40 mm. Both the anode tube, and the output waveguide including the foil are grounded.

The program KARAT [2] was used in numerical simulations of the described system. The code is fully relativistic, electromagnetic, 21/2 dimensional - two spatial dependencies (r, z) and three velocity components in a cylindrical coordinate frame, based on the particle-in-cell method.

The simulation was performed for a cathode radius of R_c = 3.4 cm. A 300 kV transverse electromagnetic (TEM) wave is input from the left-hand boundary of the modelled system, which drives the cathode negative. The rise and the duration time of the pulse are 0.8 ns and 6.2 ns, respectively. We suppose that a relatively low field (a field emission threshold of 20 kV/cm) causes space-charge limited emission from the front surface of the cold cathode towards the anode foil. On the other hand, the electron emission from the cathode side surface is neglected. These two suppositions are realistic enough if the front surface is covered with a velvet in a real experiment [3] and the side surface is well polished so that the field emission threshold would be increased above 5.10^5 V/cm (considerably lower than the values of the gradient, which can be held by the metal surfaces at short pulses).The electron beam-to-microwave power conversion efficiency ε, calculated for the pulse flat top with a duration Δt = 1.2 ns is approximately the same (about 1.5 - 2.0 %) as well as for a long flat top (Δt = 4 ns). The simulations show a 10-15 % increase of ε at Δt shortening to 0.6 ns. However, this occurs when the anode mesh transparency is high (80-90%). Considerable enhancement of the efficiency (about four times) for Δt = 0.6 ns has been calculated if the cathode side surface is brought near to the anode tube (from $\approx$ 0.5 % at cathode radius R_c=1.6cm to $\approx$ 2.0 % at R_c=3.8cm). For better understanding the mechanism of the microwave emission, we follow the method, reported in [4], where the azimuthal component of the RF magnetic field H_φ is monitored at the right-hand boundary (here in the point, - r = 3.5 cm, z = 22 cm), and the axial current I_{ax} is monitored at the anode foil. In Fig. 3 and Fig. 4 the Fourier transforms of H_φ and I_{ax}, respectively are presented. Evidently, the H_φ peak coincides in frequency with the peak of I_{ax} ($\approx$ 9 GHz), which indicates that the main source of microwave radiation are the reflected electrons, oscillating between the real and the virtual cathodes.

The frequency f_μ , corresponding to the maximum amplitude in the H_φ Fourier transform ($\approx$ 9 GHz) is higher than the TM_{01} and TM_{02} cut-off frequencies for a 4-cm radius waveguide - 2.87GHz and 6.59GHz, respectively, but lower than the TM_{03} cut-off frequency - 10.34GHz. Consequently, the dominant modes, excited in the waveguide are TM_{01} and TM_{02} .

waveguide cross-section near the end of the simulated region. The total power P_t , determined at $z = 22$ cm and averaged in the time range (1.5 - 2.2) ns is ≈ 130 MW. From 2.2 ns to 2.9 ns, P_t is approximately 80MW (Fig. 5). The decrease of P_t is considerable and is closely connected with the process of electron bunching

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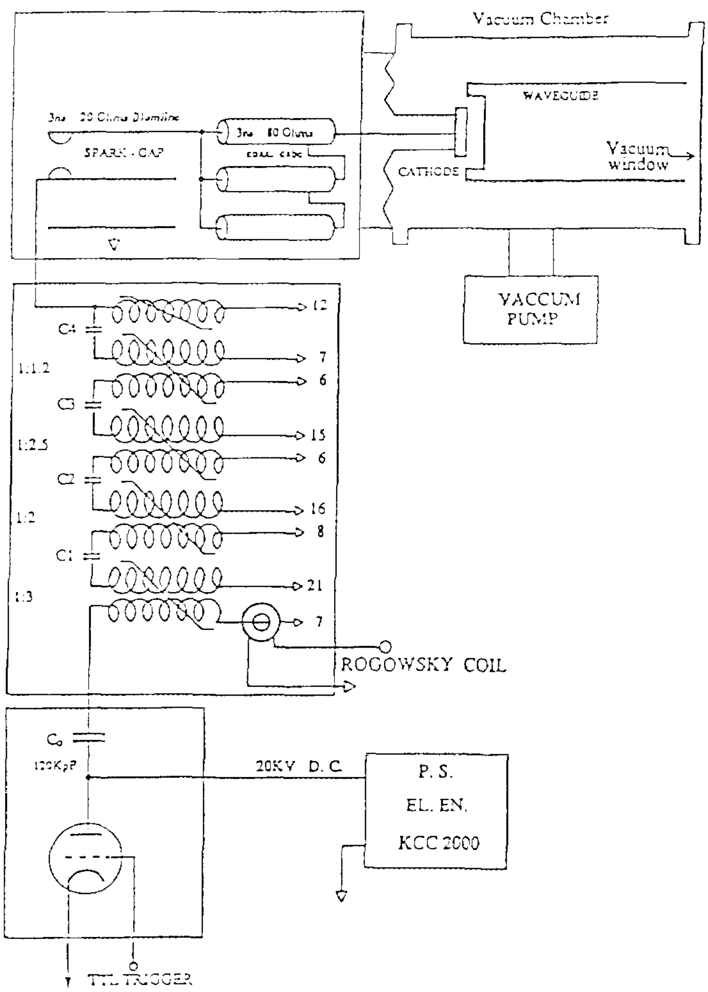

Fig.1 Schematic diagram of electron gun

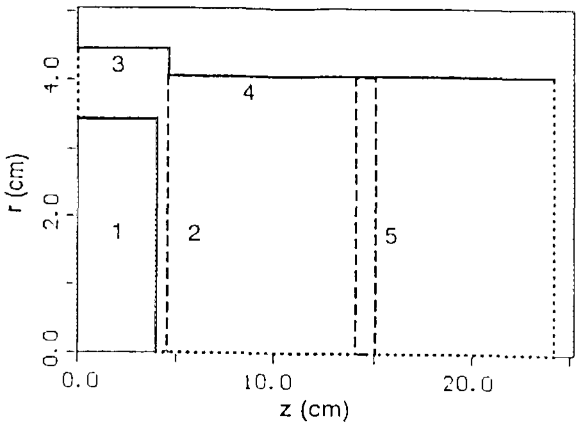

Fig. Outline of the modelled system: 1 cathode:
2 anode foil; 3 anode tube; 4 waveguide; 5 electron absorber;

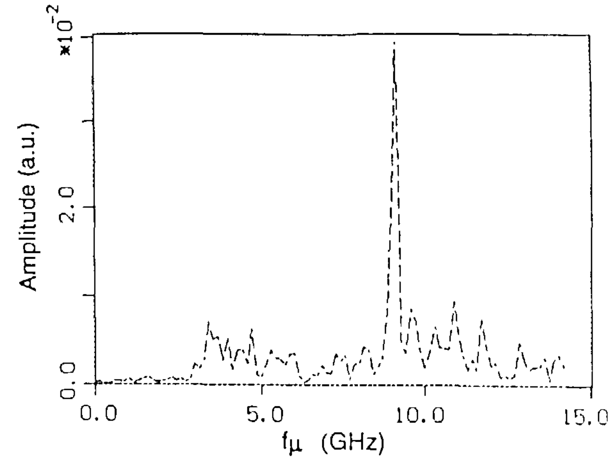

Fig.3. Fourier transform of the azimuthal magnetic field.

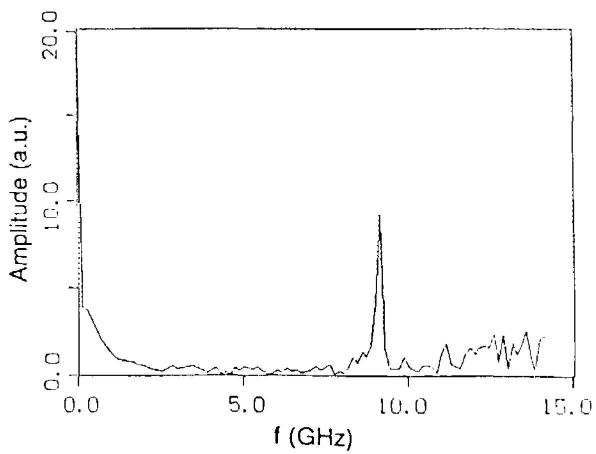

Fig.4 Fuorier transform of the beam current through the anode foil.

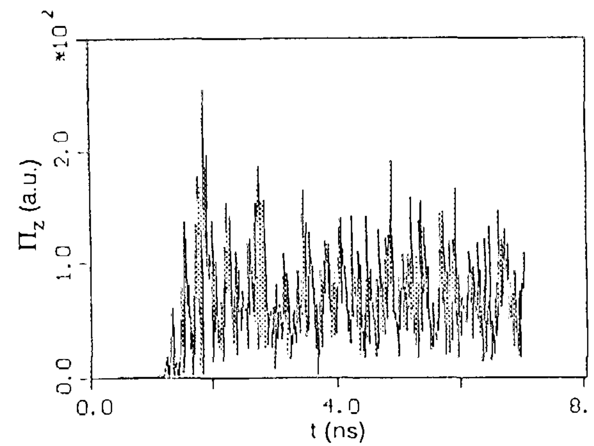

Fig.5 Time history of the poynting vector.