Beam Dynamics for Non-relativistic Electron Beam

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Summary

The two dimensional particle simulation code, PACOL, was developed to investigate the motion of the non-relativistic high intensity electron bunch in time domain. First application on the beam dynamics of the photo-emitted electron bunch in LASERTRON[1] was reported in this note and discussion was made on the maximum value of the photo-emitted current in terms of critical charge.

Introduction

A particle simulation code, PACOL, was developed and applied to the analysis of the beam dynamics of LASERTRON. Because of the high intensity of the photo-emitted electron bunch, the force of space charge and of the wake field are not negligible. Also the bunch shape affected by the space charge force changes the space and wake fields, which makes the analytical investigation difficult. Therefore, the numerical simulation was required in the high intensity and non-relativistic region.

Computational Method and Output Example

In this two dimensional code, field equation was solved by the numerical mesh method,[2] and the particle motion under the external accelerating field, V, was treated by the particle-in-cell method of plasma physics. Therefore, the self-consistency between the particle distribution and the wake field is realized in this code. Examples on the simplified model of "LASERTRON Mark-I" are shown in Fig.1.

Discussion

We found, by the simulation, following limitations on the maximum current of LASERTRON that explains the experimental results, which are shown in Fig.2.

= Surface Charge Limit = The photo-emitted charge by the single laser pulse

is less or equal to the surface charge on cathode of the area of the laser cross section, S . Thus the surface charge limit, Qsf, is defined as Qsf= E·S, where E is the electric field strength on the surface determined by V. = Space Charge Limit = The effect of the space charge force at the surface of cathode can be treated locally. Then the space charge limit is defined as the charge with which the tail of the bunch is unable to be emitted from the surface because of the Coulomb force due to the rest of the bunch. Longitudinal space charge field, Es, is given by $Es = Q / (2\varepsilon_0 S)$, with Q = total charge in bunch. Thus the space charge limit, Qsp, is defined as Es = E for Q = Qsp, therefore Qsp = 2·Qsf. But the simulation shows that the charge several times larger than Qsp can be emitted because self-field has the transverse component that makes a decrease in the longitudinal debunching force. Therefore the maximum emitted current is determined not by the space charge, but by the critical charge. Results of the simulations show that the emitted bunch with charge Q = Qsp will be accelerated by the external field with small debunching.

= Critical Charge= From above discussion, the critical charge, the maximum charge that can be emitted by the single laser pulse, is equal to the surface charge limit, Qc = Qsf.

Conclusion

It was found that the emitted current depends linearly on V as shown in Fig. 2. This fact is one of the most significiant characteristics of the LASERTRON, which is consistent with the above discussions. And there may be no severe difficulties with beam dynamics in the acceleration after the emission.

Aknowledgements

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References

(1) T.Shidara, to be published in this Proc.
(2) T.Weiland, CERN/ISR-TH/80-07, 16 JAN. 1980, CERN

—— Appendix and Figures ——

Fig.1(a) shows the model of "LASERTRON Mark I". The mesh size is 1 mm/mesh. This model is composed of three parts, acceleration gap (a), beam duct (b) and output cavity (c), where (a) and (b) are devided by the metal mesh of anode. The acceleration voltage is 100 KV for the gap of 20 mm. The bunch is composed of 40 superparticles in Z-R plane, 4 in Z and 10 in R direction. The charge takes the waterbag distribution in a disk-like bunch of 5 mm in radius and 0.6 mm in thickness at initial state. The initial velocity is 0.01 x light velocity. The dash represents the electric field induced by the bunch of 1 nC. The position of the bunch is the center of the anode and the wave front because the velocity of the bunch is about half of the light velocity.

Fig.1(b), three dimensional display is made with the third axis V, where V is the magnitude of scalar potential in the Coulomb gauge. This shows the deformation of acceleration field due to the space charge of bunch of 10 nC.

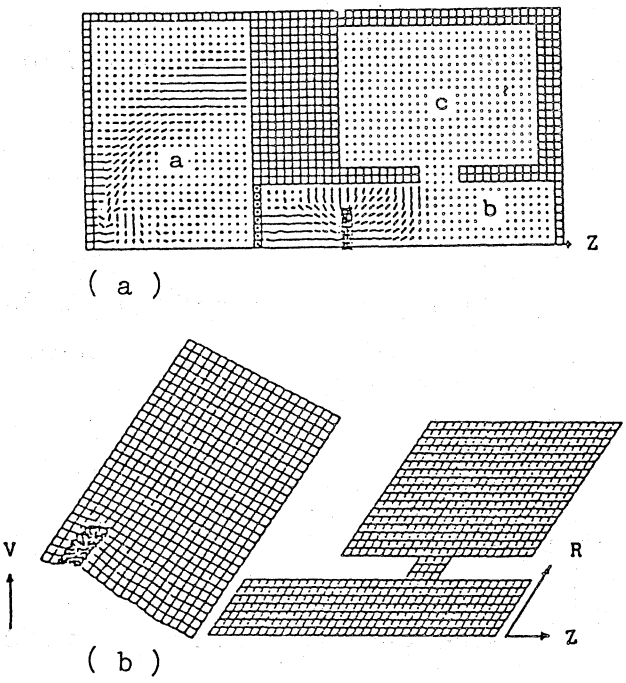

Fig.1. Output Examples

The saturation of the emission occures from two limitaions, one is from the critical charge and the other is from the laser power. When laser power is strong, the current is limited by the critical charge. Therefore, the emission current strength shows linear dependence on the accelerating voltage, as shown in Fig.2.

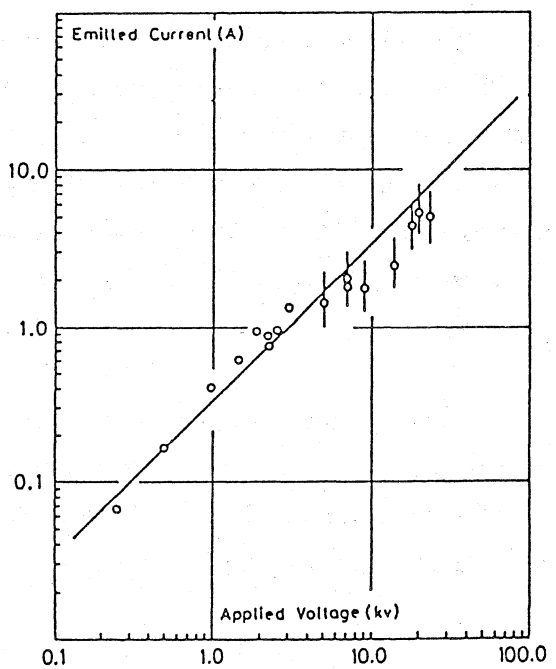

Fig.2. Voltage Dependence of Emission Current