BEAM EMITTANCE SIMULATIONS FOR HIGH GRADIENT PULSED DC/RF GUN*

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Abstract

One of the most important targets for building modern accelerators is to increase their brightness. The purpose of building a pulsed dc/rf gun is to seek high charge bunch and low beam transverse emittance injection for subsequent acceleration. These, together with a short bunch length, are key factors for enhancing brightness of accelerators. In this paper, we will present the simulation results of the beam emittance changes in dc/rf guns under different gun voltages. SUPERFISH code and PARMELA code were used to simulate the beam dynamic process in the gun. These simulations indicate that smaller beam transverse emittance (< 0.5 mm.mrad) can be obtained when the voltage on the dc gap is lower than 200 kV and the bunch charge is at 200 pc, and increasing the dc gap voltage will greatly improve the emittances.

INTRODUCTION

High gradient electron guns are expected to provide a way to suppress space charge induced emittance growth [1-6] in conventional electron photoinjectors. In an rf photoinjector, electrons are released by a short laser pulse and accelerated immediately by a high rf field to relativistic velocities, thus minimizing the emittance degradation of intensive electron beam. However, electrical breakdown and available rf power limit the rf peak field in a photoinjector. The results obtained by BNL group and elsewhere suggest that using a short-pulse dc field that is much higher in amplitude than typical rf field in a photoinjector can greatly suppress the space charge induced emittance. A dc/rf gun structure was proposed by Vander, et al. some time as for this purpose [7]. DULY received DOE funds for the studies of the dc/rf acceleration structures. We have completed a series of studies on the structures and obtained many useful results, e.g. emittance variation as a function of applied dc voltage for 0.1, 0.5, and 1.0 nC bunch charge when the dc gun gap is an ideal diode structure, voltage pulse transmission process at the entrance of the transmission line and at the gun gap, emittance evolution for the BBC gun and AWA gun with high energy injections, optimization of dc gun geometries, and so on [5, 6].

We report here further research results including the impact of the dc gun accelerating voltage on the particle motion. The entire dc/rf gun system comprises a high voltage synchronizable pulser, a high voltage coaxial transmission line, dc accelerating gap, a photocathode and an anode located in the opposite side of the dc accelerating gap, a one-cell rf cavity and a UV laser, which is shown in Reference 6. The gun will be driven by a laser at near normal incidence from an input mirror. A copper photocathode will be used since the UV drive laser is capable of producing sufficient quantum efficient with this metal. The cathode is robust compared to other cathode materials such as yttrium (Y) and magnesium (Mg), and the preparation of the cathode, e.g. cathode clean process, is relatively easy.

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DESCRIPTION OF SIMULATIONS

In these studies, a Pierce gun is adopted as the dc acceleration structure because it is very effective to get a laminar beam need for a low beam emittance [6]. For the rf acceleration, we still exploited the one cell rf cavity operated at 2856 MHz [6] for simplifying the analysis. The angle between the focusing electrodes of the Pierce guns and the longitudinal direction (z-axis) is fixed at 67.5° during the simulations.

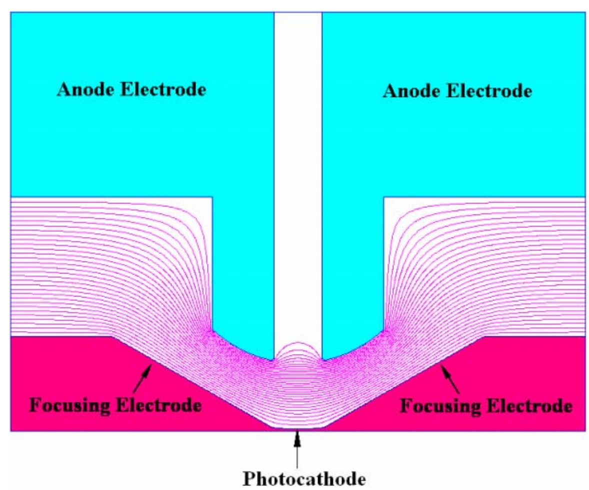

Figure 1: Diagram of the dc gap with SUPERFISH field plotted.

The diameter of the utilized area of the photocathode is 1 mm. The actual diameter of the cathode is 1.1 millimeter, which is ten percent larger than that of the utilized diameter of the photocathode, providing a margin for the laser beam. The diameter of the anode aperture is 1 mm. A schematic of the dc acceleration gap is shown in Fig. 1. Although a larger aperture will avoid the collision of the electrons with the wall of the aperture, it will also distort the electric field in the dc gap, reduce the strength of the field on the surface of the cathode surface and increase the leakage of the field to the opposite side of the anode back plane, all of which are disadvantageous for to the purpose of minimizing the transverse emittance. Since the anode is located in the opposite side of the back plane of the rf cavity, electron beam will be accelerated by the rf field once it passes through the anode aperture. The length of the anode aperture can not be too long because the beam emittance increases very fast in such a transportation channel lack of focusing forces.

Simulations assumed a bunch charge of 200 pC with a uniform ejection from the surface of the photocathode. A short bunch length of 5 ps was used. The flat-top of the voltage pulse that is used to accelerate the bunch, including the pulser's jitters, must be sufficiently long to hold the entire bunch length. But too long a voltage pulse will lead to the degradation of dielectric strength between the photocathode and the anode [8-11], where electric field is on the order of hundreds of mega-volt or even giga-volt. Therefore, a synchronizable pulser is very important for keeping the accurate timing of particle emissions while keeping the voltage pulse short [P. Chen, et al., this conference].

SIMULATIONS OF DC/RF GUN

The PARMELA model started with the gun fields generated by POISSON. The electrons are generated with a uniform transverse profile. Thermal emittance was not considered in the simulations. Pierce dc guns with different acceleration voltages were designed. Specifications of the guns are described in Table 1.

Table 1. DC Gun Part Description

Gun Name	Gap Voltage	Cathode Curvature	Anode Curvature	Anode Aperture Length	DC Gap Length
	(kV)	(mm)	(mm)	(mm)	(mm)
lc1	120	2.300	1.477	4.70	1.00
lc2	140	2.576	1.654	5.39	1.11
lc3	160	2.847	1.829	5.40	1.21
lc4	180	3.108	1.996	5.13	1.32
lc5	200	3.362	2.159	5.10	1.42
lc6	250	3.971	2.550	4.85	1.66
lc7	300	4.550	2.922	4.61	1.90

It is seen from Table 1 that the curvatures of the photocathode and the anode become large gradually with the increment of the acceleration voltage. It reveals the fact that electrons accelerated under a higher voltage will need a smaller compensation injection angle, which is used to counteract the initial space charge dispersion forces that exist right after the electrons emerge from the photocathode's surface. The anode aperture length is designed to be larger than 4.5 mm for preventing the leakage of the rf field and thus maintaining the accuracies of the simulations.

Simulations on DC Gun Only

Four different Pierce guns, lc1 to lc4, were simulated with the PARMELA code first to observe the variation of the beams' transverse emittances (Xn) and root-mean-square (rms) beam size (Xrms) during and right after the dc guns' accelerations. This is important for us to design the acceleration structure following. Simulations are ended at 6 cm from the photocahode. The results of the computations are shown in Fig. 2.

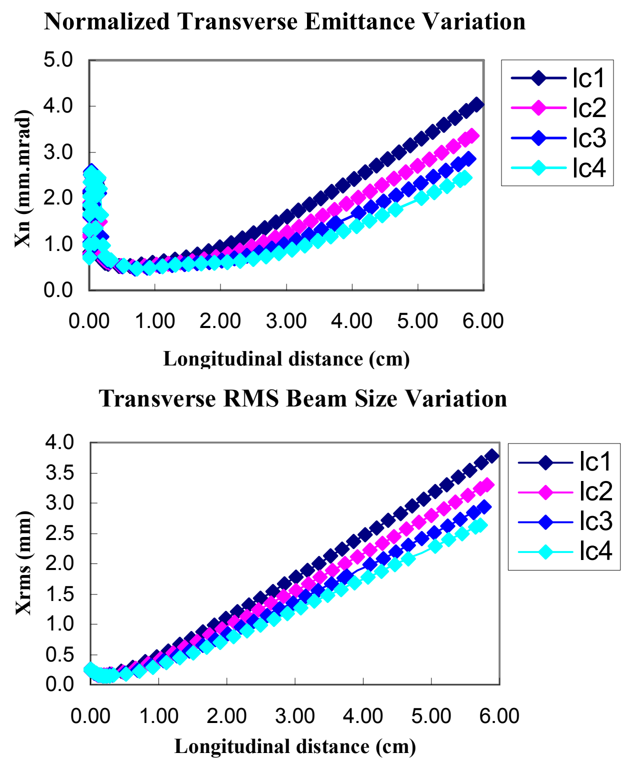

Figure 2: Beam properties in and after dc guns for Gun lc1 to lc4: (a) Xn variations; (b) Xrms variations.

It is seen from the Fig.1 (a) that Xn for all of the four guns dramatically expands once the photoelectrons emerge from the surface of the photocathode but is soon suppressed by the high gradient field acceleration. In the following drift space, Xn changes smoothly in the locations near the anode but deteriorates rapidly in farther locations. Serious expansion of Xrms can also be observed farther from the gun acceleration gap in Fig. 2 (b). These facts reveal that the rf cavity should be put in a location near the dc acceleration gap in order to diminish the emittance and reduce the beam size. Long drift path between the dc acceleration gap and the rf cavity will be a risk factor inducing an additional emittance and beam loss.

The trends shown in Fig. 2 also reveal that a higher acceleration voltage will improve the Xn and Xrms greatly. It was viewed from the figures that both the normalized transverse emittances and the transverse sizes would dwindle steadily with the increase of the gap accelerating voltage.

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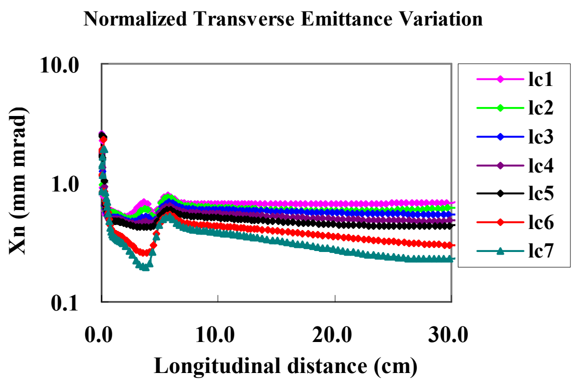
Simulations on the Entire DC/RF Guns

Before presenting the simulations on the entire dc/rf guns, we would mention that the smallest Xn obtained by us in the single rf cavity acceleration was 1.1 mm·mrad at 15 cm from the exit of the cavity (including the coax waveguide/drift tube), a point where measurement could be taken in actual tests (roughly 30 cm from the photocathode), and the Xrms along was as high as 4.1 mm (see reference 6).



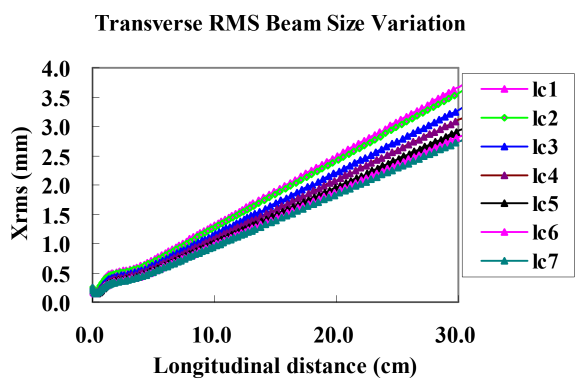


Figure 3: Beam properties for the entire dc/rf guns. The dc guns are labeled with Gun lc1 to lc7: (a) Xn variations; (b) Xrms variations.

To improve electron beam properties further, we designed several dc injection guns, as shown in Table 1, and put each gun right before the rf cavity. These guns work mainly in a relatively low acceleration voltage because we still lack of understanding in the low end of the high gradient acceleration. PARMELA simulations on the dc/rf guns with the electron injections from the seven dc guns (Gun lc1 to lc7) to the rf cavity have been done separately, starting from the photocathode and ending in a 30-cm length. The simulation results are illustrated in Fig. 3.

From Fig. 3 (a), it is observed that the Xn at the end of the simulation (30 cm) decreases steadily as the dc acceleration voltage rises up while the Xrms is suppressed once again, the trends that we already saw in the dc gun calculations. In addition, the values of the Xn and Xrms for all seven guns are smaller than their counterpart of the rf gun. When Gun lc4 and Gun lc5, whose acceleration voltages are not higher than 200 kV, are used as the dc injection parts, the final values of Xn are less than 0.5 mm·mrad. The smallest value of Xn obtained with Gun lc7 as dc injection even reaches 0.23 mm·mrad, nearly five times less than that of the rf gun indicated before. These facts clearly indicate that it is very effective to reduce the emittance through the high-energy injections of the electron beam into the rf acceleration cavity for further acceleration, even though in the simulations the injection voltage is at the low end of the high gradient acceleration.

SUMMARY

DC/RF guns were simulated with the PARMELA code and SUPERFISH (POISSON) field input data. The results of these simulations show that the dc/rf gun structure can greatly improve the beam emittance and beam size even the dc acceleration voltage is as low as 120 kV. The critical factors that impact the final transverse emittance and the final beam size are the dc gun geometry, dc gap voltage and drift space between the dc gap and the rf cavity.

REFERENCES

[1] T. Srinivasant-Rao, et al., AAC workshop, AIP Conference Proceedings 398, NY 1997, P. 7307.
[2] T. Srinivasan-Rao, et al., J.Opt. Soc. Am.B8, p294, 1991; F. Villa, AAC96, Lake Tahoe, AIP398, pp.739-746, 1997.
[3] K. Batchelor, et al., 6th EPAC, June 22-26, 1998, Stockholm, Sweden. P. 791.
[4] F. Zhou, et al., PAC 2001, Chicago, P. 2266-2268.
[5] D. Yu, et al., PAC 2003, Portland, P. 2132-2134, May 12-16, 2003.
[6] P. Chen, et al., PAC 2005, Knoxville, P.3679-3681, May, 2005.
[7] M. J. van der Wiel, Proc. 2nd ICFA Adv. Acc. Workshop, UCLA, Nov. 1999; S.B. van der Geer, et al., Phys. Rev. E, Vol 65, 046501 (2002).
[8] G. A. Mesyats, et al., Pulsed Electrical Discharge in Vacuum, (Springer-Verlag, 1989), p61.
[9] B. Juttner, et al., Proc. iii Int'l Symp. on Discharge and Electrical Insulation in Vacuum, Paris, France, 1968, p. 209
[10] F. Villa, Advanced Acc. Concepts: 7th Workshop, Lake Tahoe, CA, October 1996, AIP Conf. Proc. 398:739-746, 1997.
[11] T. Srinivasan-Rao, et al., BNL 65748 ; pres. 8th Workshop on AAC, Baltimore, MD, 6-11 July (1998); AIP Conf. Proc. 472 (1999), Wes Lawson, ed.