MEASUREMENTS OF TRANSVERSE EMITTANCE FOR RF PHOTOCATHODE GUN AT THE PAL*

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Abstract

A BNL GUN-IV type RF photo-cathode gun is under fabrication for use in the FIR (Far Infrared) facility being built at the Pohang Accelerator Laboratory (PAL). Performance test of the gun will include the measurement of transverse emittance profile along the longitudinal direction. Precise measurement of the emittance profile will provide powerful tool for the commissioning of the 4GLS (4th generation light source) injectors based on the emittance compensation principle. We are going to achieve this with the use of Pin-hole plate based Emittance-Meter that can be moved along the longitudinal direction. In this article, we present design considerations for the Emittance-Meter which is capable of measuring emittance as low as 1 mm mrad.

INTRODUCTION

A BNL GUN-IV type RF photo-cathode gun for FIR project is under construction in PAL. The beam will be produced by a Copper cathode with a combination of the frequency tripled Ti:sapphire laser in August of 2005. To make high efficiency in the SASE (Self-Amplified Spontaneous Emission) lasing scheme, the electron beams should well overlap with the radiation field. An estimation shows that in order to achieve saturation at 3 Å with 3 GeV beam, the transverse normalized rms emittance must be less than 1.2 π mm mrad [1]. For the low emittance beam, the emittance compensation scheme is essential for the design of photoinjecotr.

The emittance compensation typically involves two complementary stages: the rotation of phase space for each slice in the solenoid and the realignment of slices and fast acceleration in the booster. Essentially, the principle of the emittance compensation by solenoid is the balance between the repulsive forces due to space-charge and external focusing forces. After the beam goes through the solenoid magnet region, the beam is blowed up by space-charge force if there is no booster linac [2,3]. Thus a booster is needed to fast accelrate the beam to a relatively high energy at which the phase space is frozen and the beam is emittance dominated. To shift the second emittance minimum to the exit of the booster where the beam is emittance dominated, Serafini and Ferrario suggested a matching condition [2] for properly matching the space-charge dominated beam from the gun to the booster,

$$\sigma' = 0, \tag{1}$$

$$\gamma' = \frac{2}{\sigma}\sqrt{\frac{I_P}{2I_A\gamma}}, \tag{2}$$

where σ' is the rms transverse spot size, I_P is peak current of the beam, I_A =17 kA is Alfven current. The booster matching point will be investigated by our experiments for optimizing the emittance compensation process i.e., by the emittance characterizations for various longitudinal position which will be performed with the Emittance-Meter using Pin-hole plate and slits.

EXPERIMENTAL SETUP

Our electron beam parameters are shown in Table1. The beam parameters depend on the Laser parameters and RF power and phase.

Table 1: Beam Parameters at Exit of RF PC Gun

Parameter	Unit	Values
Beam Charge	nC	1.0
Beam Energy	MeV	5.6
Bunch Length	ps	10.0
Beam Radius	mm	1.5
Peak Current	A	100.0

Fabrication of Photocathode RF Gun

A BNL GUN-IV type 1.6 Cell RF photo-cathode gun with a resonant frequency of 2.856 GHz is under fabrication. The Cathode is fabricated by precision machining with mirror polishing. The exact cavity dimension for the resonance is obtained by repeating rough cutting and measuring with aluminium model cavity. Then the real cavity is fabricated with tuned dimension. The cavity dimension is determined by simulation with 2D code SUPERFISH to achieve 2.856 GHz resonant frequency and electric field symmetry, and the dimension is further calibrated by Gao's formula to take into account tuning hole, wave-guide port, pumping port, and Laser port. According to Gao's formula [4] if the perturbation is small $\delta\omega = (\omega - \omega_0)$ then,

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$$\delta\omega = \frac{\omega_0}{4U}\int_{\Delta\nu}(\mu_0 H^2 - \varepsilon_0 E^2)d\nu\ , \qquad (3)$$

where ω_0 is resonant frequency, ω is perturbed frequency, U is stored energy in the cavity, H , E is magnetic and electric fields in the small volume. Eq. (3) shows that the change of the cavity volume makes the resonant frequency shift. In our case, the gun cavity includes the laser input ports and the wave-guide ports, so there are several sources for resonant frequency shift and no analytical formulae alone can predict this with satisfactory accuracy. Thus, we repeated the cutting and measuring until the desired dimension of our cavity is decided.

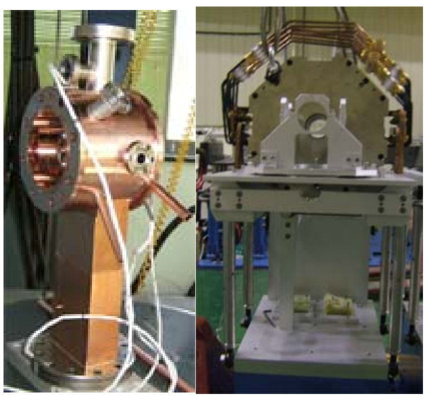

Figure 1. The RF Photo-Cathode (PC) Gun is brazed in the PAL (left) and the solenoid magnet and the stand is fabricated (right).

Fabrication of Solenoid

We obtained solenoid field profile using POSSION code for our solenoid fabrication. The emittance compensation process in our injector is confirmed with the PARMELA code. The longitudinal magnetic field at the cathode is almost 0, but in order to minimize its contribution to emittance we added bucking coil to make it to be exact 0. The mechanical axes of the solenoid and the real field profile can be different due to misalignment of each coil [7]. For measuring the amount of the mismatch of the axes, precision filed measurement stand is set up, and now the measurement process is being performed. The symmetry of radial field will be measured for estimating the mismatch of the axes.

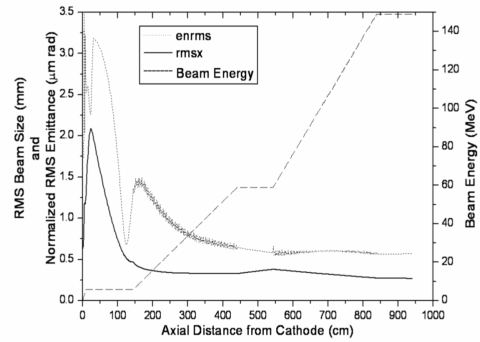

Figure 2. The beam size, emittance, and energy of our beam along the RF PC gun with the solenoid field profile is simulated by PARMELA code.

Laser Systems

The laser system for the RF PC gun is installed in the clean room with class 1000 and 0.25℃ temperature stability at the PAL. The laser system consists of oscillator, regenerative amplifier with gain medium of Ti:Sapphire, second and third harmonic generator, and pulse stretcher. The output wavelength of the laser system is 267 nm (UV region) and the peak power at the wavelength of interest is 250 μJ. The pulse width can be changed from 0.5 ps to 15 ps by dispersive pulse broadening through a fused silica medium. The repetition rates of our laser system are 30 or 60 Hz and the output of the laser illuminates the cathode repeatedly.

Figure 3. Ti:Sapphire laser system with 267nm wavelength is installed.

DESIGN OF EMITTANCE-METER

We have designed the Emittance-Meter which is movable along the beam axis with bellows, which will be used to demonstrate the emittance compensation predicted by theory and simulation [2,3]. Transverse emittance after solenoid magnet along the beam axis will be measured by the Emittance-Meter. Designed Emittance-Meter is shown in Figure 3, the left side part is RF PC gun, the solenoid magnet, the Laser incident chamber, the screen chamber and right side part is the

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Emittance-Meter. The Emittance-Meter consists to two long bellows, the pin-hole plate chamber, the YAG screen chamber.

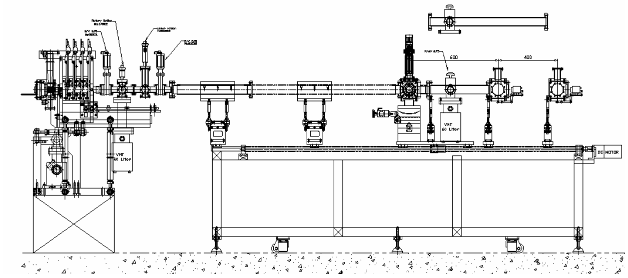

Figure 4. The left side part is the RF PC gun assembly with RF PC gun, solenoid, Laser incident chamber, and beam diagnostic chamber. The right side part is the Emittance-Meter with the bellows, pin-hole plate chamber, and YAG screen chamber.

Axial Moving

The long bellows is used for the transverse emittance measurement from 0.9m to 2.1m position measured from the cathode. The length of the bellows can be changed from 0.54m to 1.54m without vacuum breaking. One or two nipple can be used to extend the scanning region for wide search. In the last part, we will put another bellows to make cancellation the vacuum force in the front part bellows. We will check the position of Pin-hole chamber with CCD camera and a long scale attached on the shelf.

Pin-hole and Slit Plate Chamber

Pin-hole and Silt are fabricated by high power Laser micro-drilling with 30 um, 40 um, and 50 um hole diameter and same silt widths in tungsten plate with 0.5 mm thickness. The plate in the Emittance-Meter is designed to be changeable at the specific experimental position with stepping motor. We can compare the emittance value to each pin-hole size and slit width. The sizes of the pin hole and the slit are determined by considering the Signal to Noise Ratio (SNR) and the acceptance angle when the beam goes through the plate [5]. Also, very small size hole should be aligned on the beam axis for beam measurement, because if the hole is not aligned, the beam is dumped on the tungsten plate. We designed to realize the alignment art with goniometric motion, rotary motion, and linear motion with high accuracy stepping motor. The single pin-hole scanning method will be used in the beam waist region with x and y directional linear motion [6].

YAG Screen Chamber

YAG screen resolution reported in Ref [6] is 20μm, although the grain size of the YAG screen is known to 5 μm. The YAG screen chamber is put on another boat which can be moved independently with respect to the Pin-hole chamber. The distance between the Pin-hole chamber and the YAG screen chamber should be adjustable to obtain good resolution data of the beamlets. There will be a bellows between the Pin-hole screen chamber and the YAG screen chamber, so the distance between the two chambers can be varied. CCD camera will be used to record the image data for the YAG screen with frame grabber.

FUTURE WORK

The experimental plan with the Emittance-Meter is to measure the emittance oscillation in the drift region in our injector for many experimental conditions to find optimized operating condition for our injector. Firstly, we can vary the magnetic field to find the appropriate evolution of emittance for realization of the emittance compensation by the booster accelerator. Secondly, the RF phase at the laser incident moment can be shifted to find the best operating condition of our injector. Thirdly, the charge of our beam can be changed by changing the laser power. In extremely low charge (several pC) and when the bunch is short (<1ps), the emittance growth contributed by space-charge force and RF force is negligible, so we can investigate the effect of thermal emittance which is a fundamental limit of the photo cathode gun. We will make a code to automate the data acquisition and analysis. In next year, we will extend this Emittance-Meter design to measure the evolution of slice emittance which is very crucial to SASE FEL facility with movable spectrometer.

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