EMITTANCE MEASUREMENT WITH UPGRADED RF GUN SYSTEM AT SPRING-8

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Abstract

A single cell S-band RFgun has been developed at the SPring-8 since 1996. The minimum normalized beam emittance, measured with double slits' scanning method in 2002, was 2.3 πmm·mrad at the exit of the gun cavity with charge of 0.1 nC/bunch [1]. In 2004, we installed a following accelerator structure to investigate beam behavior of the whole injector system [2] [3]. In this paper, we report emittance measurement results of upgraded system, using variable quadrupole magnet method. The minimum emittance of 2.0 πmm·mrad with a net charge of 0.14 nC/bunch were able to be measured.

INTRODUCTION

We have been studying an RFgun system since 1996. The S-band cavity is single-cell type with copper cathode, which has two RF ports in order to realize symmetrical electro-magnetic fields [4]. This feature causes low Q value, which produces short filling time. Hence this cavity has an advantage in high gradient acceleration. In 2004, we achieved maximum field gradient of 187 MV/m with chemical etching treatment [5] .

Because our previous works on this system were for only the gun cavity, investigation of beam emittance as a beam injector was limited. Therefore, we rebuilt shielding room and additionally installed one accelerator structure to the cavity system between 2003 and 2004. Legally limit of beam energy was up to 30 MeV.

Main purpose of the upgraded RFgun test bench is to realize low emittance electron beam source, which means the whole system including gun cavity and the first accelerator structure.

Outline of the test bench is shown in Fig. 1. The single-cell gun cavity, two solenoid coils, and the first energy spectrometer are located before the 3-m long S-band accelerator structure. On the previous test bench without including the accelerator structure, we measured emittance by using double slits' scanning method. Thus, we should have installed the slits before the accelerator structure. Though, for low emittance beam generation, the entrance point of the accelerator structure should be designed to overlap with a point of emittance minimum. This point depends on the strength of solenoid coils and about 1.3 m far from the gun cavity in our system. This is too short to install the slits, thus it was impossible to install slits. Although energy measurement before the accelerator structure is important for operation and investigating beam dynamics, thus we choose an installation of the energy spectrometer, so that the entrance of the accelerator structure was designed to be 1.4 m from the cathode.

A triplet quadrupole magnet and a profile monitor for emittance measurement, and a second energy spectrometer were installed downstream of the accelerator structure.

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EMITTANCE MEASUREMENTS

Emittance measurements were performed with a variable quadrupole method. The measurements setup is illustrated in Fig. 2. As for variable quadrupole method, we measured electron beam size while varying strength of a quadrupole magnet. These data as a function of the magnet's strength can be fitted to a quadratic function only if the quadrupole magnet is singlet. The magnet is triplet for transporting beam to beam dumps located downstream. However, for emittance measurements, we use this magnet as a singlet. The data are fitted to following equation;

$$\sigma^2 = AQ^2 + BQ + C, \tag{1}$$

where Q is strength of the quadrupole magnet, σ is beam size. Then, we can obtain normalized transverse emittance;

$$\epsilon = \gamma\beta\frac{\sqrt{4AC - B^2}}{2L\,(L + D)}, \tag{2}$$

where L is a length between the singlet and a profile monitor where beam size are measured, D is an effective longitudinal length of the singlet. (See Fig. 2.)

A screen of a profile monitor is an alumina fluorescence sheet (Desmarquest AF995) with a thickness of 0.15 mm. A CCD is 1.3 mega-pixels IEEE1394 camera (SONY XCD-SX910), which pixel size is 4.65 × 4.65 μm^2. The resolution of the image is estimated to be 37.2 μm.

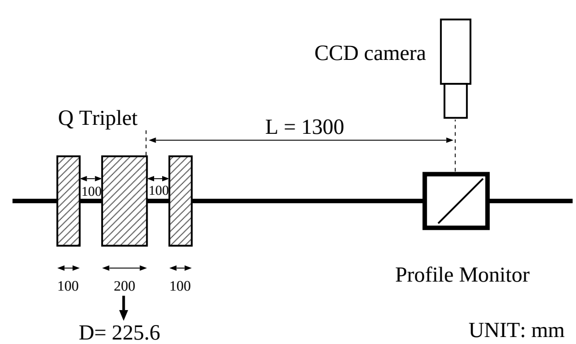

Figure 2: Measurement setup for variable quadrupole magnet method. We use only a center magnet as a singlet for emittance measurements.

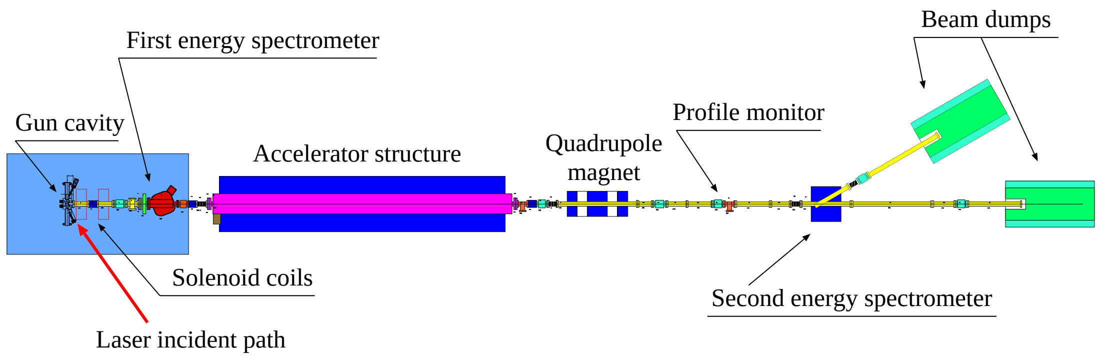

Figure 1: Top view of the upgraded RFgun test bench.

These measurements were automatically performed by a sequence program developed with LabVIEW (NATIONAL INSTRUMENTS). In this system, each instrument except for the camera is controlled via GPIB. Varying quadrupole strength, CCD image acquisition, computing beam size from the image, and fitting with a quadratic function are sequentially executed.

During these measurements, dark current was observed. It was about 40 % of total charge when net charge was 0.14 nC. With the dark current, the beam size was observed larger, which caused emittance values worse. Thus, for each quadrupole strength, the measurement system got two beam images. One was an image with laser incidence, the other without laser. The image processing were executed for each image to get rid of the effect on emittance value due to the dark current.

Parameters for measurements

The energy of the electrons at the exit of the gun cavity was 3.7 MeV with maximum electric field strength on the cathode surface of 157 MV/m. In the following accelerator structure, the beam was accelerated up to 28 MeV.

An initial RF phase for the gun cavity is important to obtain low emittance. We developed a fully 3D tracking simulation code [6] for RFgun systems. By using this code, we can calculate beam energy at the exit of the gun cavity, as a function of the initial RF phase. From comparison with these calculate results and measurements(see Fig. 3), the initial RF phase can be obtained. An initial RF phase to the gun cavity was adjusted to 85 degrees, which is an optimum value for low emittance, predicted by our simulation code. The initial RF phase ϕ_i is defined by follows;

$$\mathbf{E}_{cavity} = \mathbf{E}_0 \cos\left(\omega t - \phi_i\right). \tag{3}$$

The laser light source is THG (263 nm) of Ti-Sapphire laser system [7]. The pulse width was stretched to 5 ps. We shaped spatially the laser beam using a light shaping diffuser (Physical Optics Corporation), which divergence angle is 1.0 degree. The laser beam profile on the cathode is shown in Fig. 4. Laser beam size was estimated to be 0.6 mm FWHM.

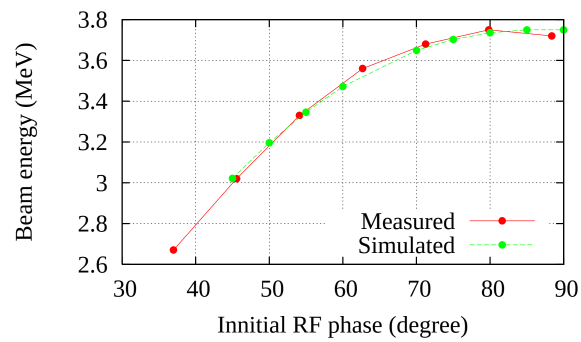

Figure 3: Comparison with measured beam energy and simulated at the exit of the gun cavity. Practically, only relative phase is observed, through absolute phase is able to be fixed by this comparison.

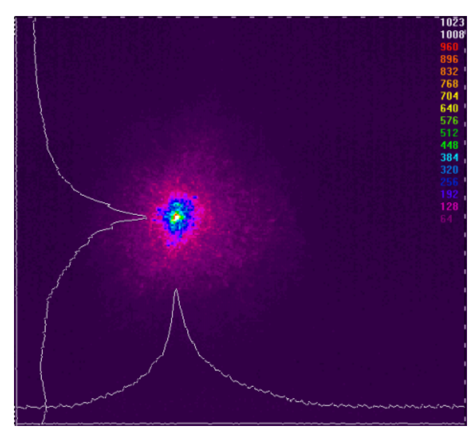

Figure 4: Laser beam profile on the cathode surface.

Solenoid coil fields are especially important for getting lower emittance. Because these fields control where the emittance minimum point is, and emittance value at the exit of the accelerator structure. We performed this optimization using our simulation code. Our solenoid coils consist of two pieces. Thus, calculation for optimization was executed with varying two solenoid coils' strength each other. This optimization was performed for each beam charge.

Measurement results

Fig. 5 shows results of emittance measurements. For each charge, solenoid coils' strength was optimized practically referring to the predicted value of the simulation code. The practical strength was agreed with the simulation value within 20% except some points (see Table 1). A minimum emittance we could measured is 2.0 π mm·mrad with a net charge per bunch of 0.14 nC.

Simulation data are also plotted in the same graph. The parameters for simulations are almost the same as measured parameters except for the laser pulse shape, which is 6ps (1σ) Gaussian in temporal and 0.3 mm (1σ) Gaussian in spatial. Note that, in these measurements, the laser incident angle to the gun cavity is 66 degrees (See Fig. 1). This oblique incidence has a bad influence on the emittance value [6]. Especially, this effect cause difference between horizontal and vertical emittance, and usually vertical emittance becomes worse in our system. The emittance values we presented in this paper are horizontal(x) one.

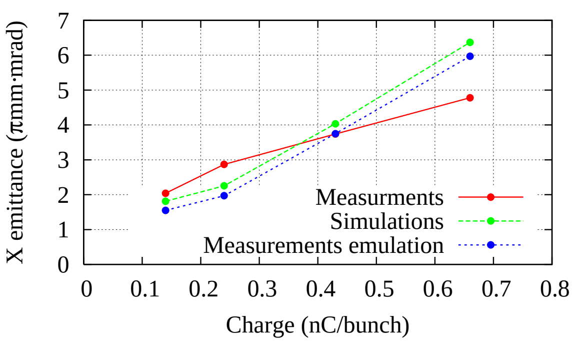

Figure 5: Comparison between measured and simulated emittance values

Table 1: Optimum values of solenoid coils. 20.0 A corresponds to about 890 Gauss at the center of the coil. As for arrangement of solenoid coils, refer [6].

Charge	**Simulated**		**Practical**	
	Coil ♯1	Coil ♯2	Coil ♯1	Coil ♯2
0.14 nC	18.0 A	32.0 A	24.0 A	27.0 A
0.24 nC	20.0 A	32.0 A	20.0 A	30.0 A
0.43 nC	24.0 A	30.0 A	20.0 A	30.0 A
0.66 nC	32.0 A	26.0 A	30.0 A	26.0 A

DISCUSSION

A quadratic fitted curve for charge of 0.14 nC is shown in Fig. 6. From fitting error, the emittance is (2.04 ± 0.034) π mm·mrad.

This variable quadrupole method is emulated by our simulation code. Focusing with quadrupole magnet are computationally emulated, and after obtaining the beam size and fitting, emittance value can be derived. These emittance values are also plotted in Fig. 5, which are about 10 % less than simulation values. (In the simulation, emittance definition is $\epsilon = \gamma\beta\sqrt{<x^2>\cdot<x'^2>-<x\cdot x'>}$.) This can be caused from the fact that distribution of x and x' are slightly different from Gaussian. It turns out that this method is able to be measured emittance within resolution of 10 %.

The measured emittance values and simulated values are slightly different each other, especially tendency of slope of the emittance curve are different. It thought to be after-effects of simulation precision, especially near the cathode.

We are preparing normal laser incidence system and 3-D shaping of the laser, for producing lower emittance.

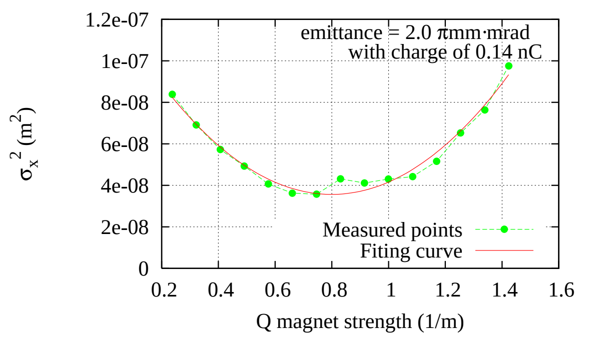

Figure 6: Measured beam size and fitted curve with the charge of 0.14 nC.

SUMMARY

Upgraded RFgun test bench was accomplished in 2004. One accelerator structure, and an emittance measurement system were newly installed. Emittance measurements were performed by the variable quadrupole magnet method. Optimization of solenoid coil fields was successful, thanks to self-developed code [6], and we were able to observe minimum normalized horizontal emittance of 2.0 πmm·mrad, with a charge of 0.14 nC/bunch, at beam energy of 28 MeV.

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