REDUCTION OF ELECTRON-BEAM EMITTANCE WITH SHAPING BOTH SPATIAL AND TEMPORAL PROFILES OF UV-LASER LIGHT SOURCE FOR PHOTO-CATHODE RF GUN

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Abstract

The spatial profile of the UV-laser as a light source for the photo-cathode rf gun has been improved, using a microlens array in a spatial filter. The improvement of the UV-laser profile is essential for emittance reduction in the electron beam from the rf gun. Since the outskirt of quasi-flattop-shaped laser beam shaped by the microlens array was cut through a pinhole with a diameter of 100 or 200 μm, the energy and pointing stability of the UV-laser became stabilized. This optical set-up made the experimental results reproducible. Consequently, it was possible to put the position of the laser spot on the cathode surface, the centre of the magnetic field induced by a pair of solenoid coils, and the central axis of pill-box-type rf cavity all together accurately aligned on an optimum-accelerating axis. As a result, we could obtain the minimum emittance value of 2π mm•mrad with beam energy of 3.1 MeV, holding its charge to 0.1 nC/bunch. The experimental data are new records for the minimum emittance for the electron beam from the single-cell-cavity (S-band) rf gun.

1 INTRODUCTION

We have been developed an rf gun as a highly qualified electron beam source to develop future X-ray light sources since 1996 in a test facility at SPring-8 [1]. Our development of this type of gun is oriented to long-lived stable system. We performed experiments to measure charge dependences of emittance of electrons from a photo-cathode rf gun at SPring-8. This experiment was performed under controlling all the system parameters (rf phase and power, temporal and spatial laser profiles on the cathode, laser pulse energy, condition of the cathode surface, and the concentred position of both solenoid magnetic field and laser spot on the cathode surface) kept constant. We chose a double-slit method for emittance measurements. This method is a multi-shot measurement, not a single-shot measurement like a so-called multi-slit measurement [2]. This indicates that the measured emittance includes shot-by-shot fluctuations of beam parameters. However, in practice the emittance including shot-by-shot fluctuations should be low enough for future applications. Currently, our system works stable without significant maintenances for one week. This situation made one-day-long measurements with the double-slit method possible. The quality of laser beam is essential to stabilize the total system and generate low-emittance beam. Especially, it needs higher stability of the pulse energy and improvements of the homogeneous spatial and temporal profiles of the UV-laser light source. We shaped the laser spatial profiles with a microlens array. Consequently, the horizontal emittance is improved from 6 to 2π mm•mrad at a beam charge of 0.1 nC/bunch. In this paper emittance is descried as normalized rms emittance.

2 EXPERIMENTAL SET-UP

2.1 Method of emittance measurement

The emittance measurement set-up for rf gun is shown in Figure 1. The double-slit emittance monitor consists of two slits with a width of 0.3 mm and a thickness of 8 mm. The distance between two slits is 46 cm. The beam charge is detected with a Faraday cup in the straight section. This monitor system can measure the emittance of beam with a resolution of 0.5 π mm•mrad. The other Faraday cup is used to measure the energy of beam.

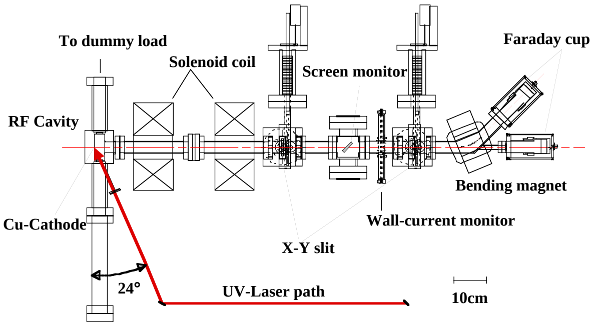

Figure 1: Beam diagnostic set-up for rf gun at SPring-8

2.2 Configuration of CPA- Ti: Sa Laser System

The laser light source for the rf gun consists of a mirror-dispersion-controlled Ti: Sapphire laser oscillator (Femtolasers Produktions GmbH) operated at a repetition rate of 89.25 MHz, a chirped pulse amplification system (Thales lasers Co., Ltd) operated at a repetition rate of 10 Hz, and the third harmonic generator system. The fundamental laser oscillates at a central wavelength of 790 nm with a spectral bandwidth (FWHM) of 50 nm. The pulse energy of fundamental laser is 30 to 60 mJ/pulse after the multi-pass amplifier. After the third harmonic generation (central wavelength: 263 nm), the laser pulse energy is 200 to 400 μJ/pulse with a repetition rate of 10 Hz. The pulse energy stability of laser has been improved up to 2 % at the fundamental and 3 % at the third harmonic generation. This stability is able to be held for one week.

2.3 Homogenizer

This laser system gives an inhomogeneous spatial profile. Therefore, we used several microlens arrays as a homogenizer. This microlens array is a collection of small hexagonal convex lenses with a pitch of 250 μm (see Figure 2). The transmission of this optical array is about 80 % in a region of ultraviolet. It makes possible to any shape laser spatial profile as a Silk-hat (cylindrical flattop) with combinations of a convex lens.

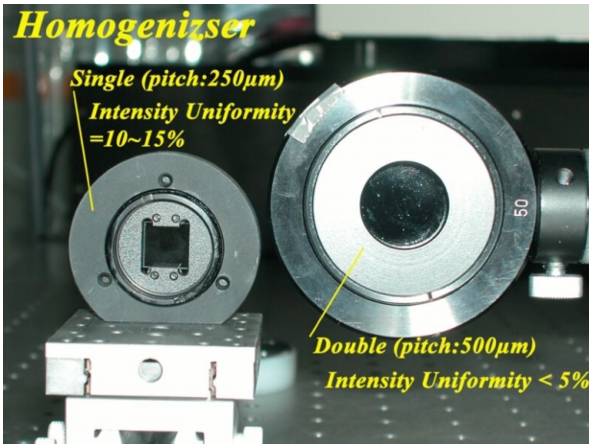

Figure 2: Picture of microlens arrays

The main difficulty to utilize this optics is how the homogenised laser profile transports toward the cathode surface with focusing. Even if the whole wave front of laser does not reach on the cathode at the same time, the laser spot on the surface should be in the depth of a focus.

3 EXPERIMENTAL RESULTS

3.1 Influence of laser spatial profile on emittance

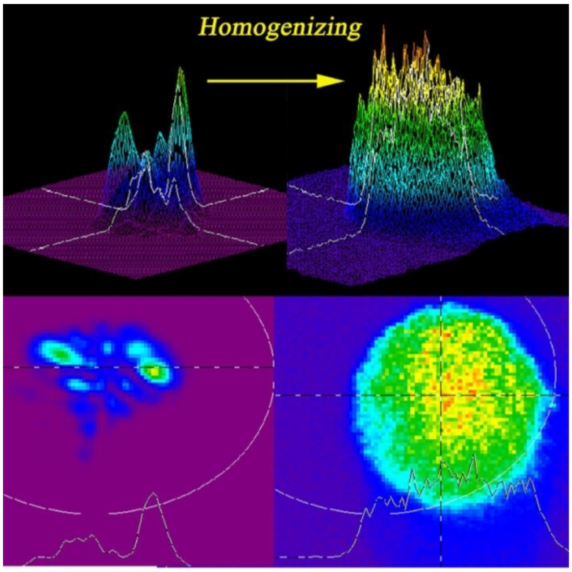

Figure 3: Improvement of the laser spatial profile

The laser spatial profile without homogenizing is shown on the left hand in Figure 3. The profile was spatially shaped by a microlens array as a quasi-Silk-hat profile (see on the right hand in Figure 3). These profiles were measured laser beam profiler (Spiricon Inc., LBA300-PC). By spatially homogenizing, the emittance has been improved from 3.3 to 2.3π mm•mrad at a beam charge of 0.2 nC/bunch. Note that both of these measured emittance values were obtained without treating as Gaussian fitting. The emittance data have a noise of approximately 5 %. In this paper, all the data except these two data are treated with Gaussian fitting. But, the emittance data with an inhomogeneous laser do not have Gaussian distributions. Empirically, we know that these 5-%-cut-emittance values are comparable to the values obtained by fitting as a Gaussian distribution.

3.2 Temporal profile of the laser pulse

The temporal profile of the UV-laser was measured by a streak camera (Hamamatsu Photonics K.K. C6138 FESCA-200) with the minimum resolution of 200 fs. In Figure 4 single-shot (right lower) and 100-shot averaged (right upper) pulse shapes are simultaneously shown. The measured pulse width of the UV-laser was approximately 5 ps (FWHM).

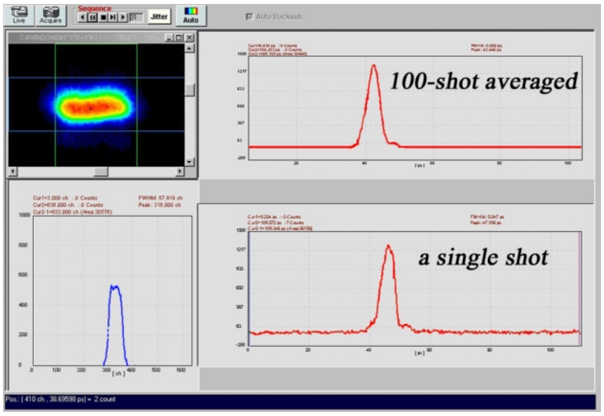

Figure 4: Streak image of the UV-laser pulse

3.3 Dependence of horizontal and vertical emittance on beam charge

The maximum field on the cathode and beam energy were achieved up to 175 MV/m and 4.1 MeV, respectively. The dark current was 0.17 nC/pulse with an rf pulse width of 0.5 μs. All the data shown in Figure 5 and 6 are taken, using the beam with energy of 3.1 MeV and the maximum field on the cathode of 135 MV/m. During these experiments, we found a dark current of 0.018 nC/pulse. The measured quantum efficiency was 5×10^{-5}. All the system parameters of the rf gun except laser pulse energy were kept constant. Here, net charge means the measured current with a laser incident subtracted by the dark current without the incident.

Each datum was treated with fitting as a Gaussian distribution. The error bars indicate just a sufficiency of Gaussian fitting.

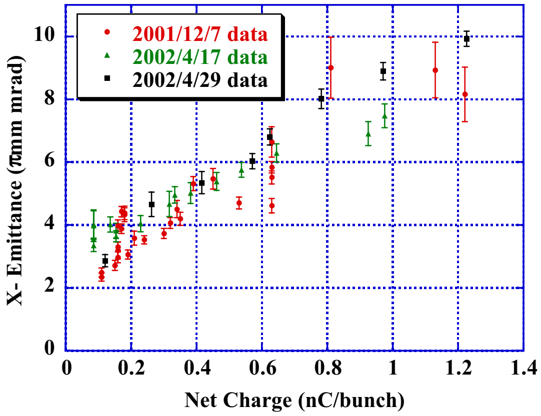

Figure 5: Charge dependence of emittance in different experimental runs: All data put here were measured, using a vertical diameter of laser on the cathode of 1.5 mm.

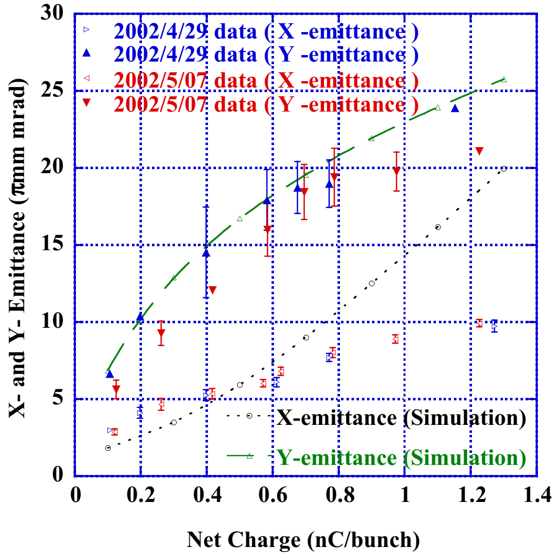

Figure 6: Charge dependence of horizontal and vertical emittance in different experimental runs: Numerical results are also shown for the comparison.

4 NUMERICAL RESULT AND DISCUSSION

Comparing data among different experimental runs in Figure 5 and 6, the data show that the experiments were reproducible. Experimental results in Figure 6 show that vertical emittance is larger than horizontal one. It due to the injection with an incidence angle of 66 degrees to the cathode surface. The round laser spot change into an elliptical spot image on the cathode. Consequently, laser power densities are different between in the vertical and horizontal directions. And also, the wave front of laser does not reach on the cathode surface at the same time. Avoiding this inhomogeneous distribution of laser power density on the cathode, we are preparing optics for a quasi-perpendicular injection with a possibly small incidence angle (almost 0 degrees).

We have developed a fully three-dimensional particle-tracking code [3] to calculate dynamics of space-charge-dominated beam. Note that thermal emittance is not taken into consider in this calculation. Measured spatial and temporal laser profiles were given as the parameters for this calculation. Additionally, the influences of incident angle are taken into account in this calculation. Comparison between experimental and numerical results is shown in Figure 6. Both results gave good agreement in a beam charge of less than 0.8 nC/bunch.

We also estimated the optimum parameter set of this rf gun with this code. Figure 7 shows that the optimal laser pulse is a rectangular temporal profile with a pulse width of 20 ps. The numerical results of the charge dependencies of vertical (green dotted line in Figure7) and horizontal (black dotted) emittance were shown in a case of the perpendicular injection. They show that there is not significant difference between vertical and horizontal emittance values. The slight deference still remains between vertical and horizontal ones. The cause of this difference is the asymmetry of the electrical fields in the different transverse directions on the cathode sueface.

According to both experimental and numerical results, temporally shaping with the optimum pulse width and the perpendicular laser injection are necessary to generate lower emittance beam. To control temporal parameters of the laser pulses, we are preparing a UV-laser stretcher and a programmable phase and amplitude femtosecond pulse shaping systems in the fundamental wavelength region using a spatial light modulator with a pair of gratings in a stretcher configuration.

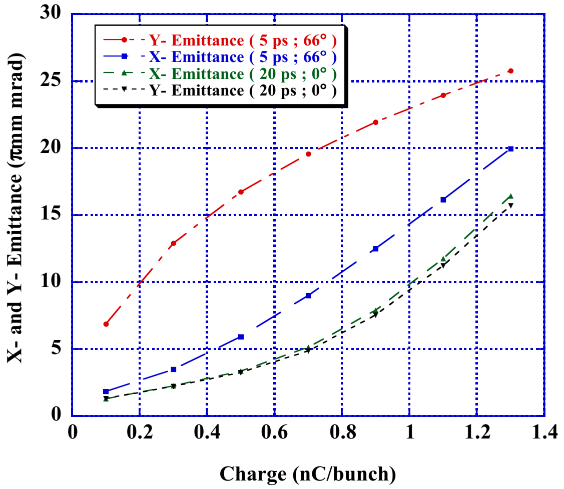

Figure 7: Comparison between different laser pulses:
(5 ps: with an incidence angle of 66 degrees; 20 ps: with an incidence angle of 0 degrees)

5 REFERENCES

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