PHOTOCATHODE RF GUN DESIGNED AS A SINGLE CELL CAVITY

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Abstract

The paper describes recent improvements of an S-band RF-gun at SPring-8. A new test bench facility for the RF gun was constructed for two main purposes. One is to add a linac after the RF gun to measure the beam emittance after the acceleration with the linac, and the other is to make another RF gun test stand mainly for the experiments of the high quantum efficiency cathode. A new RF distribution system to feed the high power RF to the two gun cavities and a linac was constructed, The positions of the two solenoid coils and the linac were optimized with PARMELA that predicted the lowest beam emittance after the linac as 2.2 πmmmrad at 1 nC/bunch. When the cavity was installed, it was reprocessed with chemical etching technique to get high quantum efficiency and could obtained good result of 8.6×10^{-5} at 263 nm. The RF conditioning was done very slowly and carefully under an automatic control watching the vacuum condition and the field gradient finally reached to 155 MV/m. The acceleration of the electron beam in the linac was successful and the energy spectrum was measured. The quadrupole scan apparatus to measure the beam emittance with a screen profile monitor and a CCD camera was installed and tested.

INTORODUCTION

The photocathode RF-gun can generate a low emittance beam because the high acceleration-field lowers the space-charge effect. It does not require a beam bunching section normally used with a thermal cathode gun because the beam bunch length is very short typically 1-20 ps. It will be applicable to an electron source for the electron-positron collider or the SASE FEL. It will be also used as an electron source for the future industrial or medial accelerators because it is much simpler and smaller than the conventional injection system.

We have been studied an RF gun of the single cell pillbox cavity, because we aimed to get a high gradient field acceleration [1]. In addition, this cavity has a good symmetry and it will decrease the beam emittance growth due to the asymmetrical RF field. The present focuses of our research are the low emittance beam generation and the high quantum efficiency cathode. For the low emittance beam generation, higher RF field was applied in the cavity and the laser was also improved to get a flat-top spatial profile. In addition, the laser and RF synchronization was carried out without PLL feedback. As the results, the beam emittance of 2 πmmmrad at 0.1 nC/bunch was already realized [2].

A new test bench for the RF gun was constructed for two purposes. One is to add a linac after the RF gun. The electron beam just after the RF gun has a longitudinal position dependence of the beam emittance and indispensable dark current. These situations make it difficult to measure the beam emittance correctly. For this reason, we thought to measure the beam emittance after the linac. The other purpose is to build an RF gun test stand mainly used for the experiments of the high quantum efficiency cathode. For high quantum efficiency, the Cs_2Te and diamond cathodes are studied. The studies of the high quantum efficiency cathode are not discussed in the paper (see ref. [3]).

RF GUN TEST BENCH

We have constructed a new test bench for the RF gun. It has a linac beam line and an RF gun test stand as shown in Fig. 1. The linac beam line consists of an RF-gun, two solenoid magnets, a 3-m linac, two bending magnets, a steering magnet, a triplet quadrupole magnet, four profile monitors and a Cherenkov light monitor. They were designed to measure the beam emittance after the beam was accelerated with the linac up to 30 MeV. The RF gun test stand (RF gun2 in Fig. 2) was constructed for the experiments of the high quantum efficiency cathode.

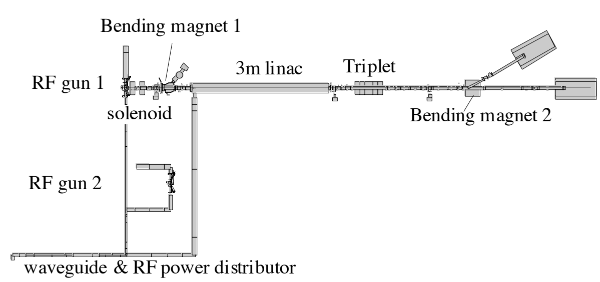

Figure 1: Outline of the RF gun test bench.

The RF system for these two RF gun cavities and a linac consists of an RF generator, a low power RF system, a klystron modulator, an 80 MW klystron (Toshiba E3712), and an RF waveguide circuit with an RF distributing and phasing system. In order to distribute the RF power, a complex RF waveguide circuit was designed as shown in Fig. 2.

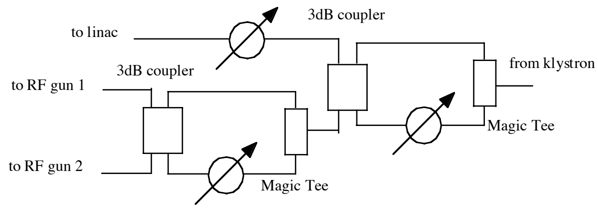

Figure 2: RF distributing and phasing system. There are two controllable high power dividers using a magic Tee, a phase shifter and a 3dB coupler. The phase shifter to the linac controls the RF phase difference between the RF gun and the linac.

As for the RF generator, the RF signal (2856 MHz) is generated from the laser oscillator pulses (89.25 MHz). The timing jitter between laser pulse and the RF signal (2856 MHz) was as small as 1.2 ps enough to operate the RF gun stably [2].

BEAM SIMULATION

To calculate the beam dynamics from the cathode to the end of linac, a simulation code PARMELA was used. The position of two solenoid coils and the distance between the RF gun and the linac were determined. The length from the RF gun to the linac was designed as long as possible, because the optics of normal injection and the energy-analyzing magnet had to be installed here. The optimized result is shown in Fig. 3. In spite of the long distance (1.2 m), the beam emittance after the linac was 2.2 πmmmrad at the beam charge of 1.0 nC.

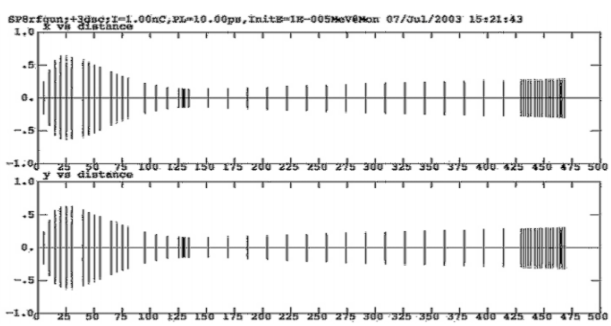

Figure 3: The beam simulation of an RF gun and a following linac with PARMELA. The laser is assumed to be normal injection to the cathode. The RF gun locates at 0 cm, two solenoids at 15.4 cm and 37.4 cm, and the linac starts at 120 cm and ends at 420cm.

RF GUN CAVITY

The RF gun cavity is a pillbox type single cell. The cathode is copper that is a part of the inner wall of the cavity. There are two RF ports, and a dummy load at the output RF port. The cavity was designed for a high field gradient. So far the maximum field gradient of 175 MV/m was achieved in the past experiment [4].

Before we installed the cavity in the new test bench, it was reprocessed with the chemical etching technique. The RF conditioning was done very slowly and carefully under an automatic control watching the vacuum condition. After RF processing for 21 days, the field gradient reached up to 155 MV/m and the cavity was operating stably.

BEAM TEST

The energy spectrum of the electron beam accelerated with the RF gun was measured, where the dark current was subtracted from total charge. The center energy is 3.6 MeV and ΔE(FWHM) is 0.3 MeV as shown in Fig. 4. The energy spectrum of the accelerated beam with the linac was also measured. The center energy is 24.4 MeV and ΔE(FWHM) is 2.0 MeV as shown in Fig.5. The beam acceleration was successful as the first step.

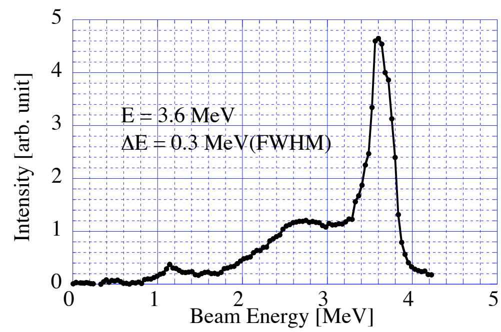

Figure 4: Energy spectrum of the electron beam after gun.

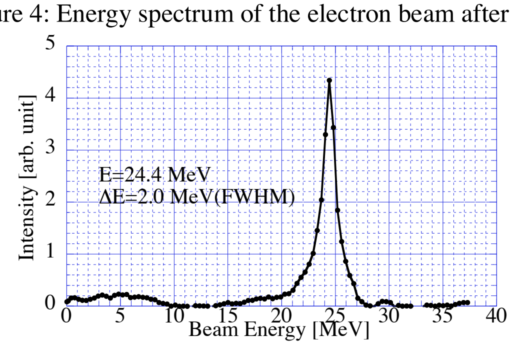

Figure 5: Energy spectrum of the electron beam after linac.

The quantum efficiency was also measured at various accelerating field. The wavelength of the input laser was 263 nm, and the pulse energy was 33 μJ. To control the polarization of the laser, a polarizing beam-splitter cube with extinction ratio of 100:1(Tp/Ts) was placed before the beam window of the cavity. Furthermore, the window has a Brewster's angle to get a perfect transmission of the parallel polarization. The beam charge was measured after the first bending magnet with scanning the energy of the beam. For this reason, total charge was obtained by integration with weighting factor. The results of the measurements are shown in Fig. 6. It shows that relatively higher quantum efficiency 8.6×10^{-5} at 155 MV/m was achieved. As the result, the chemical etching processing was found to be effective to increase the quantum efficiency of copper cathode.

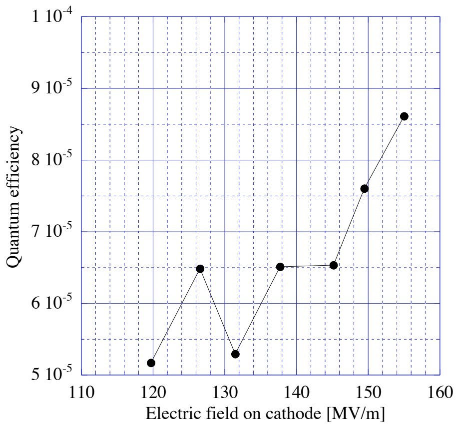

Figure 6: Electric field dependence of quantum efficiency

EMITTANCE MONITOR

The measurement of the beam emittance is a main issue of the research. When we use quad scan to measure the beam emittance, the beam size must be measured at the resolution of the order of 10 μm. To realize the fine resolution, we adopted a profile monitor with a thin screen and high resolution CCD camera. The screen is an alumina fluorescence sheet (Desmarquest AF995) with the thickness of 0.15 mm. The CCD camera is 1.3-mega pixels IEEE1394 camera (SONY XCD-SX910). It has a 1/2-inch CCD chip with 1280(H) x 960 (V) pixels, and each pixel size is 4.65 x 4.65 μm^2. To get a large depth of field, we used a telecentric lens of 1/4 magnification. The estimated resolution of the image is about 20-30 μm. The triplet quadruple lenses are used to focus the beam on the screen. The maximum magnetic-field gradient was 5 T/m. The outline of the triplet and the screen is shown in Fig 7.

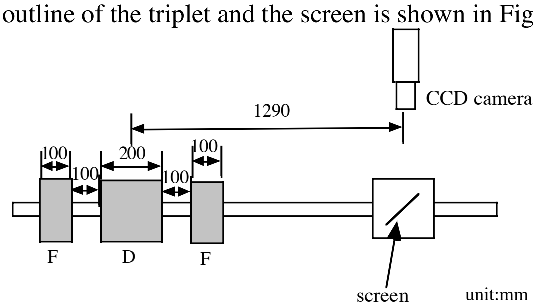

Figure 7: Outline of quad-scan measurement.

A test measurement of the quad scan was carried out. The beam was focused on the screen (Fig.8) and the result of quad scan is shown in Fig.9. Ten images for each focus length were taken and averaged. The good quadric curve indicates that the measurement was successful. Because the measurement was manually operated, it took about one hour. We are planning an automatic data taking and analysis. This will be useful to search better parameters of the lowest beam emittance.

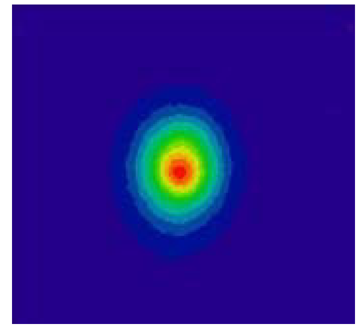

Figure 8: Beam profile (100x100 pixels) at the focus. The rms beam size is 153 μm(H) and 200 μm(V).

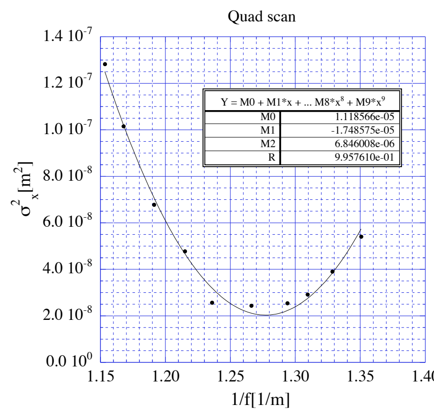

Figure 9: A test measurement of the quad scan. The beam emittance of 10.9 πmmmrad was measured with the quad scan, where f is the focus length of the triplet magnetic lenses; σ_x is the rms beam size.

SUMMARY

A new test bench for the RF gun study was constructed. The RF conditioning of the single cell cavity was carefully treated and the RF field of 155 MV/m was realized. The electron beam from the RF gun was accelerated with the linac up to 24.5 MeV. The quantum efficiency of the copper cathode was 8.6×10^{-5} at 155 MV/m. The emittance monitor with quad scan using a profile monitor and a CCD camera was installed and could measure the beam emittance properly. To get lowest emittance, the optimization of the laser temporal and spatial profiles and pulse length as well as parameters of solenoid coils and RF phase will be carried out.

REFERENCES

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