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Performance of high duty photocathode RF gun

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Abstract

A RF photoinjector for the high duty operation was designed, constructed by the BNL/KEK/SHI international collaboration and installed at the S-band linear accelerator of the University of Tokyo. This system has been used for the sub-picosecond X-ray generation and the laser acceleration. The repetition rate of the operation has been 10Hz so far, because a T^3 laser used for these applications has 10Hz repetition rate at maximum. The RF conditioning has been advanced for 50Hz repetition rate. The RF photocathode was operated at 50Hz to confirm the performance of the gun designed for high duty operation. The dark current and the emittance were measured mainly. The minimum normalized emittance measured was 3.5 π mm.mrad.

1. Introduction

Technologies to obtain high brightness electron bunches with a low emittance and a short duration have been studied with photocathode RF guns using short pulse lasers in order to apply for new technologies, laser accelerator, FEL, X-ray generation by Compton scattering and so on[1),2)]. More than ten years photocathode development and recent short pulse laser development, the photocathode is emerging as a standard laboratory tool for high brightness electron beam applications.

Laser wakefield accelerator (LWFA) expected as a compact high energy accelerator with high gradient particle acceleration has been studied[3)]. JAERI, KEK and the University of Tokyo have studied LWFA using a linac with a photocathode RF gun installed one year ago to get the low emittance and short bunched electron beam and also to accelerate electrons more efficiently.

RF photoinjector technologies have been integrated in Brookhaven National Laboratory (BNL)[2)]. Recently, 1.6 cell RF photoinjector has been developed by the BNL/SLAC/UCLA collaboration[4)]. Based on this development, the improvement for high duty operation was performed by the BNL/KEK/Sumitomo (SHI) collaboration[5)]. Major improvements were removing the RF heat using water-cooling channels and the RF seal structure of a cathode plate.

High duty operation means high repetition and/or long pulse oens. High repetition operation is required for getting good statistics for some experiments. Long pulse operation is also required for FEL experiments. For these purposes, the photocathode RF gun for high duty operation has been developed. In this paper, the results of high repetition operation are reported.

2. Experimental apparatus

The photocathode RF gun system consists of the photocathode gun with a Cu cathode, dipole magnets, a solenoid magnet, a diagnostic system with a Faraday cup and a beam profiler, and an all solid LD-pumped picosecond laser[5)].

Cooling water with the temperature control within 0.1 degree flowed through three cooling channels with 5 litters/min each to remove the RF heating and control the temperature of the gun. The RF pulse has 6MW-peak power with 5μs FWHM duration. The repetition rate was increasing, the resonant frequency of the gun was lowing slightly. In this case, the temperature of cooling water was changed to obtain the good RF return signals at each repetition rate.

The all solid LD-pumped Nd: YLF laser consists of a mode-locked oscillator and a regenerative amplifier[6)]. The oscillator with 79MHz repetition rate is LW131 manufactured by Lightwave Electronics. The regenerative amplifier was operated with 1-100Hz repetition rate. The 1057nm fundamental with about 2mJ pulse energy was frequency quadrupled to yield 263nm UV radiation with more than 100 μ J pulse energy by two BBO (Beta-Barium-Borate) nonlinear crystals. The UV light was injected to the cathode with oblique angle. The profile of light was an ellipse prior injection by using optical components to be circle at the surface of the cathode. The diameter of laser beam at the cathode was 2mm. The laser pulse duration of the 2nd harmonics was 25ps FWHM measured by a femto-second streak camera with 200fs resolution (FESCA, Hamamatsu Photonics).

The whole experimental system is shown in Fig. 1.

The electron bunches from photocathode RF gun were accelerated by a linac to about 21MeV. The sub-picosecond electron bunch duration was required for the laser acceleration and the X-ray generation. A chicane type magnetic compressor was used for bunching the electron duration from several pico-seconds to several hundred femto-seconds.

The electron bunch charge was measured by Faraday cups set after the gun, after the linac and before a spectrometer. The emittance was measured by the quadrupole magnet scan technique with a quadrupole magnet and a beam profiler after the linac. The beam profilers were phosphor screens with 1mm and 0.1mm thickness.

3. Experimental results

3.1 Dark Current dependence on repetition rate

High field gradient applied to the photocathode RF gun is great advantage to avoid emittance growth due to space charge, but the increasing dark current is disadvantage to some applications. Especially, high duty operation enhances the dark current apparently. Figure 2 shows the relation of the repetition rate and the dark current measured after the gun and setting temperature of cooling water. It can be seen in Fig.2 that the dark current increases with the higher repetition rate.

The dark current at the downstream was diminishing to less than 10% of the measured value after the gun through the beam transport, at the linac especially. That is why the most of dark current emission is different in space and temporal from the photoemission by the laser illumination.

3.2 Charge

The bunch charge was measured by Faraday cups calibrated by an ampere meter. The characteristics of electron bunch are dependent on laser injection RF phase. The bunch charge is also dependent on the laser injection RF phase. The bunch charge at the charge maximum phase vs. laser energy is shown in Fig.3. The relation between the electron emission and laser energy is almost linear in this region. The 2nC electron bunch charge was obtained with 75μJ laser energy. Quantum efficiency was $1.2x10^{-4}$. These data was obtained in accumulation of several ten bunches because that the fluctuation of the laser pulse energy was 10% at minimum. Th quantum efficiency between 10Hz and 50Hz was not changed within the resolutions of this experiment.

3.3 Emittance compensation of solenoid magnet

The solenoid magnet was set near the gun to compensate the emittance growth due to the space charge[7]. The solenoid magnet realigns each longitudinal beam slice having a different phase space angle at the downstream of the gun to diminish the emittance growth due to the linear space charge force[8]. The relation between the normalized emittance and the current of the solenoid magnet is shown in Fig. 4. The laser energy was about 70μJ and the laser injection phase was 20 degree. The bunch charge in this experiment was about 800pC. It can be seen in Fig. 4 that the current of the solenoid magnet minimizing the emittance was around 87A corresponding to 1.3k gauss at the center of the solenoid magnet.

3.4 Emittance change by linac RF phase

The linac is important to keep invariant envelope beam transport which damps the correlated emittance in order to provide the emittance compensation[8]. The relation of the normalized emittance and the linac RF phase shown in Fig. 5 was measured under the same conditions as the above ones, but the bunch charge was 200pC because of the poor laser conditioning. The crest phase where the electron bunch is accelerated to maximum energy is shown to be at-60 degree in Fig.5. It can be seen in Fig.5 that the RF phase getting the minimum emittance was not the crest phase. The minimum emittance was not measured this time because the beam spot was almost focused at the quadrupole magnet used for the emittance measurement. It is reasonable that the minimum emittance is obtained at the beam waste. The minimum emittance measured was 3.5π mm.mrad under the 50Hz repetition rate.

4. Conclusion

A RF conditioning has been performed since the photocathode RF gun installation. The 50 Hz high repetition rate operation was performed successfully. A frequency change due to thermal expansion of the gun was controlled by the temperature of cooling water.

The high repetition rate operation is fascinated for some applications. As the development of a high peak power laser with the high repetition rate, LWFA and X-ray generation experiments with high repetition rate will be performed in a few years.

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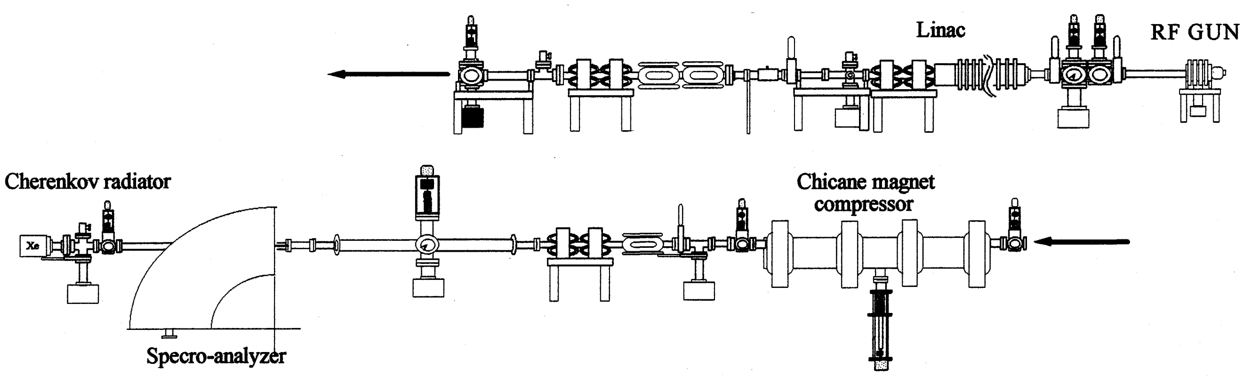

Fig.1 Experimental setup

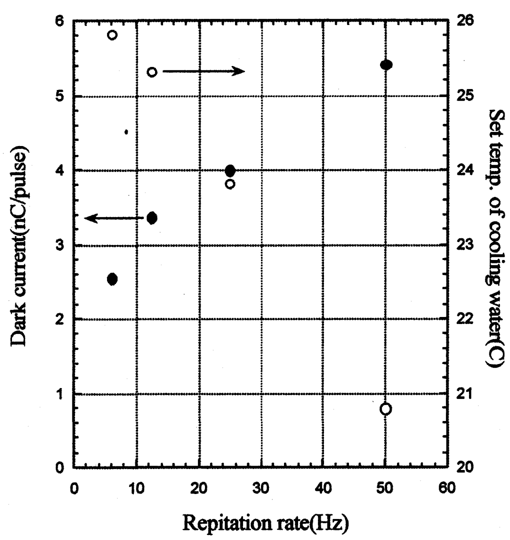

Fig.2 dark current and setting temperature of cooling water

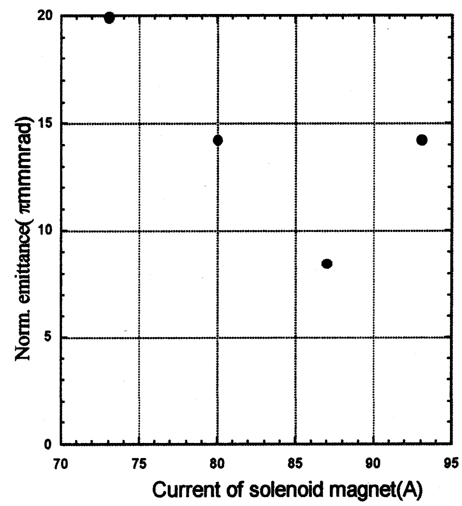

Fig.4 Emittance vs. current of solenoid magnet

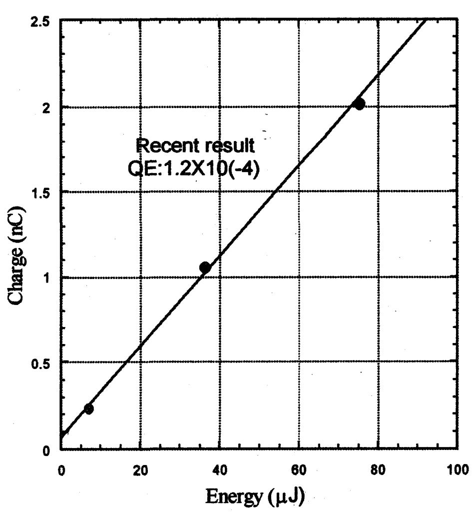

Fig.3 Bunch charge vs. laser energy

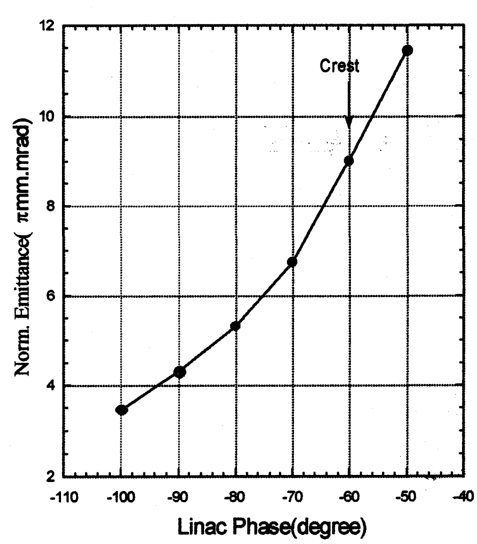

Fig.5 Emittance vs. linac RF phase