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# Properties of the electron beam generated by photo-cathode RF gun

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## Abstract

KEK-ATF is a test accelerator to establish the low-emittance multi-bunch electron beam required by the future linear collider. In ATF, electron beam is generated by combination of a thermionic electron gun and a bunching system. Electron beam generated by this system, however, is unstable due to fluctuations of many components, e.g. buncher RF phase etc. On the other hand, Photo-cathode RF Gun is the best candidate in future high-current, short-pulse, and low-emittance electron sources. These features meet the requirements of the future linear collider. Photo-cathode RF gun might be a good replacement of the current injector of ATF. To examine this possibility, we have performed a test experiment that a RF gun is set in ATF instead of the conventional thermionic gun. We have confirmed that the RF gun has enough performance as the electron source for ATF in single bunch operation.

## 1 INTRODUCTION

KEK-ATF is a test accelerator to establish the low-emittance multi-bunch electron beam for the future linear collider. ATF consists of 1.5 GeV S-band linac, a beam transport line, a damping ring, and a diagnostic extraction line.

In the conventional ATF configuration, electron beam is generated by a thermionic gun. Bunch length is shrinked from 1 ns to around 15 ps to fit S-band acceleration by a couple of 357 MHz Sub Harmonic Bunchers, and a TW buncher. Multi-bunch with 2.8 ns separation is implemented by applying 357 MHz RF signal on the gun grid.

In ATF, the energy and orbit fluctuation of the electron beam caused by the bunching section(two SHB cavities, and a TW buncher) has been observed. It disturbs precise study for the beam property. In addition, the beam stability itself is an essential point to realize the linear collider. In the linear collider, multi-bunch method is assumed to get high-current beam keeping the peak current low. In that case, the long range wake field would be serious because of the short aperture of the X-band accelerating structure that will be used in the linear collider main linac. The long range wake field makes the beam emittance growth that kills the luminosity. A special accelerating structure, DDS (Damped Detuned Structure) is employed to control the wake field precisely to suppress the emittance growth. To work this method well, the bunch intensity should be equal by less than 1.0%. Therefore, in a view of not only the study efficiency, but also the linear collider realization, the beam stability is an important issue.

Photo-cathode RF gun is the best candidate in future high-current, short-pulse, and low-emittance electron source. The bunch length made by the RF gun is determined by the temporal structure of laser. Because 10 ps pulse laser is ordinary, we can easily obtain 15 ps length electron beam with the RF gun without any bunching devices. We might be free from the bunching instability and could improve the beam stability with the RF gun.

## 2 THE BEAM LINE

Fig. 1 shows a schematic view of ATF linac injector modified for the RF gun test.

BNL RF gun IV [1] is placed at the first end of the beam line. Up to 15 MW of 62 MW S-band RF power provided by Toshiba E3712 klystron is fed to the RF gun through 6dB directional coupler. Rest of the power is distributed to the first accelerating structure, L0.

The RF gun is followed by a solenoid magnet that suppress the emittance growth by the space charge effect.

Faraday cup is set to measure the emitted current. The Faraday cup is usually off the beam line and remotely loaded on it. In the same load system, a screen monitor is also implemented. Other two screen monitors are set after L0 and in end of the injection system. The last screen was used to measure the emittance. Three Quadrapole magnets stand side by side to perform emittance measurement by the Q-scan method.

An integration current transformer, ICT is placed after L0. Several ICTs are also set at downstream, e.g. the end of linac. By comparing these data, the beam transmission of a certain part can be evaluated.

With the analyzer magnet, the beam momentum can be measured. The beam energy was typically 78 MeV.

Three BPMs are distributed along the injector section, in downstream of the solenoid magnet, front of L0, and rear of L0.

Optical Transition Radiation, OTR monitor is implemented to measure the bunch length. OTR light generated by the interaction of the beam and the in-

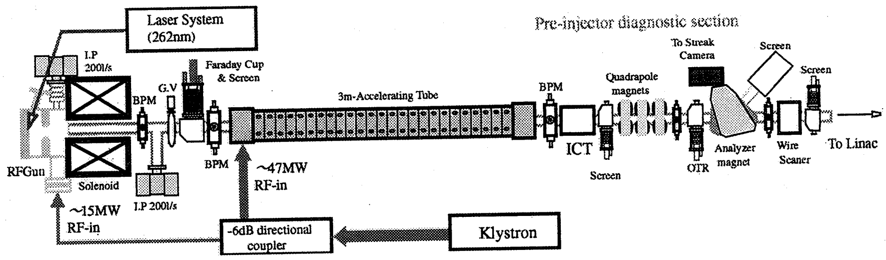


Figure 1: Electrons induced by laser are immediately accelerated by RF field in the RF gun. RF power from a klystron is distributed to the RF gun and the accelerating structure. Many instrumentation devices such as screens, etc. are implemented.

serted SUS plate is observed by a streak camera that can measure the signal with sub-pico second resolution.

A wire scanner is introduced to obtain the beam profile. 50 $\mu m$ gold coated tungsten wire scans the beam line along vertical and horizontal axes. By integrating the gamma ray emitted by the wire, the beam profile is re-constructed. This monitor provides another way to measure the emittance.

This injection system is followed by the regular accelerating sections. 16 structures accelerate the electron beam up to 1.3 GeV with the field of 25 MeV/m. The electron beam is then transported and injected to the damping ring.

## 3 LASER SYSTEM

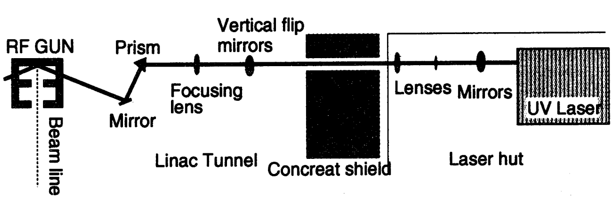


Figure 2: It shows a schematic view of the laser system for the RF gun. The laser module is placed in the laser hut constructed behind of the concrete shield. The laser spot size and position can be controlled by moving the final focus lens and the final deflecting mirror.

In RF gun, electrons are induced by the photoelectron effect on Cu cathode. As the photon source, 262nm UV light made by Nd:YLF laser was used. Fig. 2 shows the schematic view of the laser system. Laser hut was constructed on the other side of the linac tunnel across the concrete shield. The laser hut temperature is controlled 21° C to keep the laser condition. In the laser hut, the laser is expanded to approximately 20mm diameter by combination of f=-35 and f=300 lenses. The laser is then introduced to the linac tunnel through a hole on the concrete shield.

In the tunnel, a lens (f=1000) focuses the laser on the gun cathode plate. The lens is mounted on a movable stage to change the spot size of the laser on the gun cathode. The RF gun is operated usually at the spot size of 2.0 $\sim$ 3.0mm diameter.

The laser is injected to the gun cavity with angle of 67.5 degree from the cathode plane as shown in Fig. 2. The spot on the cathode becomes therefore an ellipse rather than a circle. In such case, the beam emittance will be worse than that with a circle spot. A prism is introduced to correct the spot shape on the cathode to be a circle.

The final mirror to deflect the laser to the gun cavity is remotely movable to control the laser position on the cathode in both axes, vertical and horizontal respectively.

The laser power was 100 $\mu$J at the output port of the laser module. In front of the RF gun view port, it was 55 $\mu$J.

## 4 BEAM PROPERTY

Fig. 3 shows beam current measured by ICT at downstream of L0 as function of the gun RF phase. The current marks its maximum of 1.6 $\times$ $10^{10}$electron/bunch around 20 °. It decreases down to 0.5 $\times$ $10^{10}$electron/bunch at 70 °.

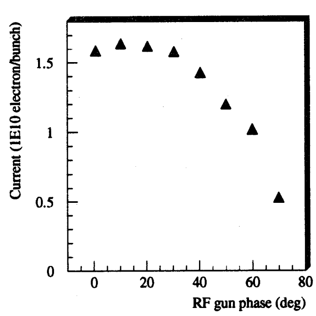


Figure 3: Beam current by ICT at L0 out is shown as function of the gun RF phase.

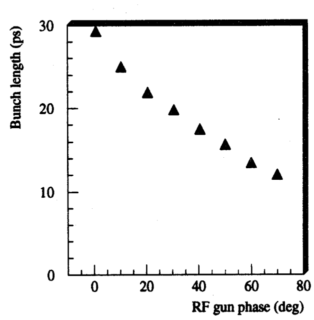


Figure 4: Bunch length measured by Streak camera is shown as function of the gun RF phase.

Fig. 3 shows bunch length as function of the gun RF phase. Bunch length is obtained by observing the optical transition radiation light with a streak camera. The bunch length is 30 ps at 0 ° RF phase and decreased down to 11 ps at 70 °.

From these results, the operation condition of the gun RF phase was determined to be 40 ° where the bunch length of 17 ps fits to S-band acceleration with enough current, 1.4 $\times$ $10^{10}$electron/bunch.

Fig. 5 and 6 show the emittance as function of the solenoid magnet current and the gun RF phase respectively. The beam emittance was measured at downstream of L0. The emittance was evaluated by Q-scan

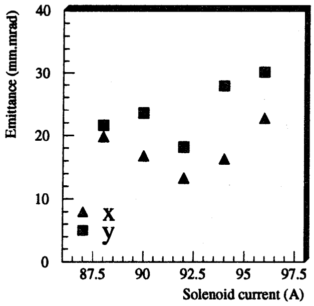


Figure 5: Beam emittance measured by Wire scanner at L0 out is shown as function of the solenoid magnet current.

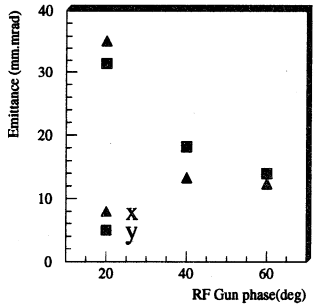


Figure 6: Beam emittance measured by Wire scanner at L0 out is plotted as function of the gun RF phase.

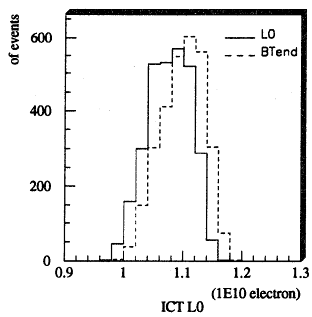


Figure 7: This figure shows distributions of the beam current measured by ICTs. The solid and dashed lines corresponds to those at L0 out and BTend respectively.

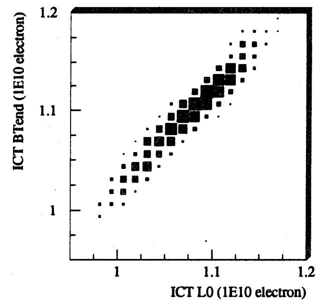


Figure 8: Horizontal and vertical axes show the beam current measured at L0 out and BT end respectively. Area of the boxes is plotted as proportional to the number of entries.

method. Horizontal and vertical beam profiles were taken with the wire scanner.

Both emittance on horizontal and vertical are minimized at 92 A of the solenoid magnet current. By toggling gun RF phase at this condition, both emittance at 60 ° are smaller than those at 40 °. These results, 12.4 $\pi$mm.mrad and 14.0 $\pi$mm.mrad on horizontal and vertical respectively, are the smallest emittance in our study. The beam current was $5.3 \times 10^9$electron/bunch.

# 5 INJECTION STABILITY

The electron beam generated by the RF gun is but also fully accelerated by the linac up to 1.3 GeV and injected to the damping ring. Fig.7 show the beam current measured by ICT at downstream of L0 (solid) and the end of the beam transport line, BTend (dashed). The peak position of BTend is slightly larger than that of L0 out, but it could be a systematic error of the ICTs. The transmission efficiency from L0 out to BTend is therefore 100% within the errors. The distributions, however, look too broad as compared with the ICT resolution, typically several %. In fig. 8, the same data are plotted in a two-dimensional plane. The horizontal and vertical axes show ICT output at L0 out and BTend respectively. By looking this plot, the beam current is highly correlated between these ICTs. It means that there is no any significant fluctuation between ICT at L0 out and BTend, but there is some fluctuation of the initial beam current.

There are several candidates to cause this fluctuation, jitter of laser intensity, laser timing, laser position, RF amplitude, RF phase, and solenoid current. There was no correlation between RF amplitude and the beam current fluctuation. RF phase is stabilized by a feed-back system within 1% of S-band. RF is then not the criminal. It is hard to imagine the solenoid current moves so much. Some of laser instability is the most suspectable candidate at this moment.

The efficiency of the stored current in the damping ring to the injected current was limited up to 50%. The reason of this bad store is power supply fail of a magnet in the damping ring. The injection efficiency was, however, almost 100%. Therefore, the injected current would be fully stored if the ring was operated in the usual condition. With the RF gun a beam loss free operation would be possible.

# 6 SUMMARY

We performed a test experiment to examine the feasibility of the photo-cathode RF gun to KEK-ATF. By using Nd:YLF UV laser with 10 ps pulse width, 12 $\sim$ 20ps length electron beam was obtained. The required beam current, $1.0 \times 10^{10}$electron/bunch was easily achieved.

We confirmed the horizontal and vertical beam emittance of 12.4 $\pi$mm.mrad and 14.0 $\pi$mm.mrad respectively at $5.3 \times 10^9$electron/bunch.

The electron beam generated by this RF gun system was injected to the damping ring. The beam was transported and injected into the ring without any significant beam loss. The beam intensity jitter might be caused by some laser instability.

In contrast to the operation with the usual thermionic gun, the RF gun system has many advantages on the beam emittance, the injection stability etc. The beam intensity jitter could be stabilized by careful tuning on the laser module.

Even these nice features, we can not switch to the RF gun. The multi-bunch beam can not be made with the RF gun at this moment because 10 ps continuous pulses separated by 2.8 ns laser light does not exist. If such laser was realized, the photo-cathode RF gun was a perfect replacement of the current thermionic gun system.

# 7 REFERENCES

[1] X.J. Wang et al., Proc PAC 1995 (1995) p890