Multi-bunch beam generation by Photo-cahode RF gun

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Abstract

KEK-ATF is doing R&D establishing high-current and low-emittance multi-bunch electron beam for the future linear collider. We have developed a new injector with the S-band photo-cathode RF gun. We use the Nd:YVO_4 357 MHz mode lock laser to generate the multi-bunch beam with 2.8 ns bunch spacing. CsTe cathode was introduced because of the high Q.E. more than 1%. In this article, we report the schem of the injector and basic beam properties.

INTRODUCTION

KEK-ATF is a test facility to study the low-emittance multi-bunch electron beam and beam instrumentation technique for the future linear collider. That consists from 1.5 GeV S-band linac, a beam transport line, a damping ring (DR), and a diagnostic extraction line.

In the linac, the beam instability and the beam loss at the injection to DR had been an issue. It has been considered that the long beam tail in longitudinal direction made the energy tail which was lost at the injection. In addition, a small fluctuation on the bunching RF (two SHBs and a TW buncher) caused the beam instability.

We have examined a photo-cathode RF gun in summer 2001 as the injector of ATF to solve the problem. The RF gun cavity was 1.6 cells BNL type, same type as that we currently used. The laser was Nd : YLF UV laser with 10 ps bunch length, single shot. The cathode was a conventional copper surface. The electron beam obtained from this RF gun was therefore single bunch, but the stability was excellent. The transmission from the gun to DR was almost 100%, i.e. all of the electron bunch was successfully stored in DR without any significant loss. The intensity fluctuation was however up to 10% due to the power and pointing jitter of the laser. This study demonstrated that the basic performance of the RF gun was marvelous as ATF injector. The intensity jitter was not a big difficulty because the thermionic gun system had intensity jitter that was not significantly small. In addition, the laser jitter would be improved in future by technological evolutions anyhow.

The important issue is the multi-bunch generation. The multi-bunch electron acceleration is one of the essence to realize the large luminosity in linear collider. Therefore, the multi-bunch electron beam is necessarily in ATF R & Ds.

To demonstrate the multi-bunch electron beam generation by RF gun, we have performed a test experiment again in Summer 2002. In this study, we introduced "multi-bunch laser". This laser can generate continuous laser pulse with 2.8 ns spacing, several μJ/pulse power. We have introduced a new cathode material, CsTe that has high Q.E. to produce enough current with this limited laser power.

The combination of the multi-bunch laser and CsTe cathode make the multi-bunch generation from RF gun possible and the test in Summer 2002 was successfully done. We have concluded that we abandoned the thermionic gun and switched to the RF gun officially. As the permanent system, the photo-cathode RF gun injector has operated since October 2002.

BEAM LINE

The RF gun complex consists of RF gun cavity, Nd:YVO_4 mode lock UV laser, and CsTe cathode system.

The cavity is made from Oxygen free copper. The resonance frequency is tuned to be S-band central frequency, 2856MHz. The cavity has two cells operated in π mode, so the electric field in these cells is opposite to each other. Because the first cell is electrically terminated at the center of the cavity by the cathode plate, the electric field on axis becomes very strong and right perpendicular to the cathode surface. Due to this field, the emitted electron is immediately accelerated up to relativistic momentum.

This gun cavity was fully made in KEK including the machining, blazing, and welding. The cavity inner surface was finished by super-fine lathe with diamond bite. This technology has been originally established by X-band accelerating structure R&D group in KEK to suppress the RF discharge break down in the accelerating structure. Fig. 2 shows dark current emitted from RF gun as function of input RF power. "new" and "old" guns were processed with the fine and conventional lathes. This figure shows this fine machining has a big advantage to reduce the dark current more than 1/10.

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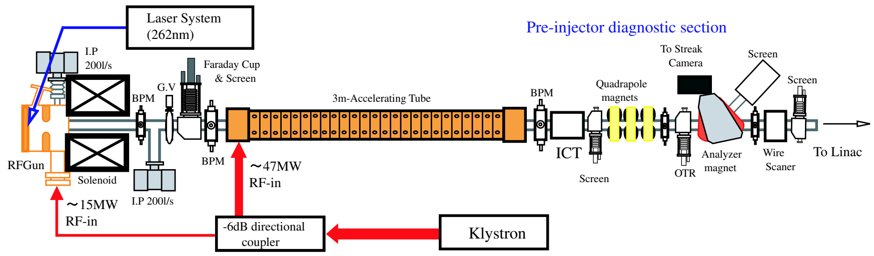

Figure 1: Layout of the injector. RF power from a klystron is distributed to the RF gun and the accelerating structure. Many instrumentation devices such as screens, etc. are implemented. In actual system, the cathode load-lock system is connected directly to the gun cavity.

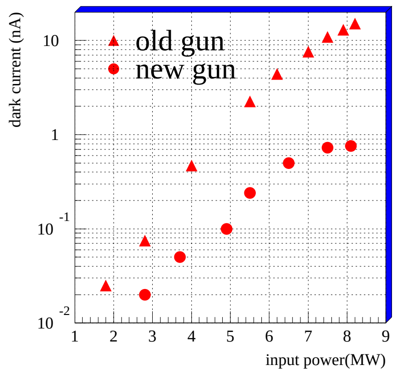

Figure 2: Dark current from the gun cavity as function of input RF (1.6 μs duration and 12.5 Hz reputation). The current gun is shown as "new gun".

Nd:YVO_4 1064nm (IR) seed laser with 357 MHz mode locking generates continuous laser pulse with 2.8 ns spacing. The power is 410mW CW. By fast switching of the transparency of Pockels cell, a part of the continuous pulse train is clipped out. A couple of Pockels cell assemblies are used. The fast Pockels cell that has less than 1ns rise and fall time mainly decides the bunch number in a train. Another Pockels cell, slow one, has less than 3ns rise time. This cell has a roll to suppress the amplitude of the laser pulse cut by the fast one further. As a result, the clearly clipped bunch train is obtained. By shifting the clipping timing, the bunch number can be varied from 1 to 100[1]. This number is currently limited by the radiation safety regulation. This clipped laser pulse train is then amplified by four amplifiers pumped by Nd:YAG followed by SHG(Second Harmonic Generator) and FHG (Fourth Harmonic Generator) crystals converting the laser from IR (1064 nm) to UV (266 nm). The UV laser is finally obtained.

Laser power and pulse length are several μJ/pulse and 12ps in FWHM typically. This laser light is then introduced to Linac tunnel and passes through a telescope assembly to decrease its spot size to 1/6. The laser spot size on the cathode depends on the laser condition, but it is expected between 1-3 mm on cathode.

At first, the laser was injected oblique to the cathode with 67.5 degree. This is an easy way, but the laser spot is expanded in the horizontal direction more than twice. The pointing instability is also enhanced in this direction. Then we have changed the injection scheme in this April to head-on. As we mentioned later, this modification improved the beam property.

[1] 20 for DR injection mode

To get enough beam current with the limited laser power, we use CsTe high Q.E. cathode. Since this material is easily damaged by exposing to air, the evaporation of Cs and Te on the base material (Mo), the transferring the cathode, and setting the cathode plug to the gun cavity are all performed in vacuum. We constructed so called "load-lock" system to perform these procedures. CsTe cathode marked more than 10% as initial Q.E., but it rapidly dropped down to less than 5% by feeding RF power into the cavity. Q.E. was then slowly decreased in time, but it was kept more than 1% for several weeks. For details of the cathode performance and the load-lock system, please refer to Terunuma's article [1] in this proceedings.

The schematic layout of the injector system is shown in Fig. 1. The laser system and the load lock system are omitted because they are too complicated to draw in a picture. The RF gun 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. ICT(Integrated Current Transformer) and WC(Wall Current monitor) are also implemneted to measure the beam current.

Three Quadrapole magnets stand side by side at downstream of L0 to make the β matching with the following regular accelerator section. They are also used for emittance measurement by Q-scan method with the wire scanner beam profile monitor.

The beam momentum is measured with the analyzer magnet. The beam energy was typically 80 MeV.

Optical Transition Radiation, OTR monitor is implemented to measure the bunch length. OTR light generated by the interaction of the beam and the inserted SUS plate is observed by a streak camera that can measure the signal with sub-pico second resolution.

BEAM PROPERTY

Fig. 3 shows the beam profile in time measured by Wall current monitor. These profiles were taken with number of bunch set to 1, 10, and 20. From these figures, the multi-bunch electron beam is generated successfully. The bunch clipping was marvelous, so the contrast between the

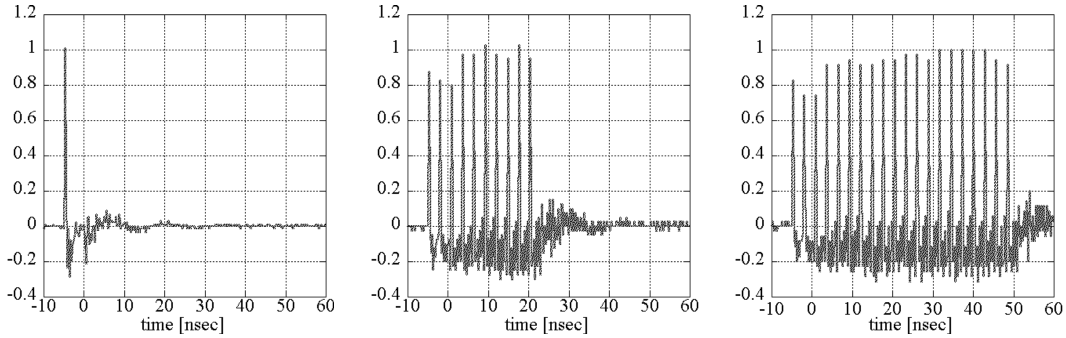

Figure 3: Beam profile in time measured by Wall current monitor. From left, the bunch numbers are set to 1, 10, and 20.

clipped and removed part was very good. The intensity flatness in a train depends on the noise condition of the Pockels cell driver circuit.

The laser power was 2 - 3 $\mu J/bunch$, and the cathode Q.E. was around 1%, so that more than $4.0\mathrm{e}+10\mathrm{electron/bunch}$ could be obtained. Even though, the maximum current is limited up to $2.0\mathrm{e}+10\mathrm{electron/pulse}$ by the radiation safety regulation. The current is therefore adjusted to be $1.0\mathrm{e}+10\mathrm{electron/bunch}$ or less by reducing the laser power.

To decide the operation condition, we measured the beam current as function of the RF phase. The beam current was maximized at some phase, but the optimum phase is 20 deg. early for shorter bunch and lower emittance. For more details of the operation condition of RF gun, please refer to [2].

The energy spread at the injector was measured by momentum analyzer system. That was 4.9% FWHM by oblique laser injection, but it was improved to be 1.9% by head-on laser injection. 1.9% energy spread was obtained by optimizing the system to the lowest energy spread, but there was "trade off"s to the beam current, the beam emittance, etc. Usually, the system is operated around 2-3% energy spread.

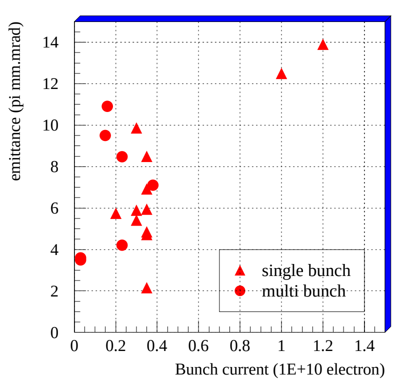

Figure 4: Beam emittance data are plotted as function of bunch current. The triangle and circle symbol show the single- and multi-bunch data respectively.

The transverse beam emittance was measured by the wire scanner with Q-scan method. This device scans beam with a thin tungsten wire (50μm diameter) and observes scattered gamma rays with a photo- tube. By plotting the gamma ray flux as function of the wire position, the beam profile is reconstructed. Taking several beam profiles with different phase advance (different Q-magnet current), we extracted the twiss parameter and the emittance. The analysis was done with SAD beam optics analysis suite. Fig. 4 plots the normalized emittance as function of bunch current. These data were all taken with head-on laser injection. The emittance measured with the oblique laser injection was not analyzed well, but that was even larger than 10 π mm.mrad. The triangle and circle symbol show data of single- and multi-bunch respectively. The data are scattered, but the emittance looks larger for larger bunch current. Any significant difference was not observed between single- and multi-bunch data. The laser spot size was guessed as 1-3 mm, but it was not controlled well.

By observing OTR light with a streak camera, the bunch length was measured to be between 6.4 and more than 15 ps in FWHM. Although this performance is even enough for ATF specification, the stability is rather important and it was not investigated yet. Possible sources making this instability are the laser jitter. Currently we do not have any real time monitoring device for laser, that should be introduced for further study.

The intensity jitter of the gun emission could be less than 3%, but it may be up to 10%. It depends on strongly the laser condition. Also in this view, controlling and monitoring the laser is very important.

SUMMARY

We have developed RF gun complex to generate multi-bunch electron beam with 2.8 ns bunch spacing. It was implemented by 1) Nd:YV0$_4$ 357 MHz mode lock laser with pulse clipping, 2) CsTe high Q.E. cathode with the load-lock system, and 3) RF gun cavity manufactured in KEK with state-of-the-art technology. The excellent multi-bunch electron beam was obtained from 1 to 20 bunches. The beam property was measured and confirmed that the basic requirements in ATF are satisfied.

To improve the beam quality more, controlling and monitoring the laser condition is very important. We are currently planning to introduce a real time laser monitoring device such as power monitor, profile monitor, etc.

REFERENCES

[1] N. Terunuma et al., WP-10 in this proceedings

[2] M. Kuriki et al., "Properties of the electron beam generated by photo-cathode RF gun", 13th Accelerator science symposium proceedings, 2001