RF gun using Laser-triggered photocathode

* H. Akiyama, Y. Otake, T. Naito, Y. Takeuchi and M. Yoshioka

KEK, National Laboratory for High Energy Physics,
1-1, Oho, Tsukuba, Ibaraki, #305, Japan
* The Graduate University for Advanced Studies
1-1, Oho, Tsukuba, Ibaraki, #305, Japan

Abstract

An RF gun using laser-triggered photocathode has many advantages as an injector of the linear colliders since it can generate a low emittance and high current pulsed beam. The experimental facility for the RF gun, such as an RF system, a laser system and a photocathode have been fabricated to study the fundamental characteristics. The dynamics of the RF gun has also studied by the 1D sheet beam model.

Introduction

In KEK, the Japan Linear Collider, JLC, is being vigorously pursued[1], with typical parameters corresponding to c.m. energy 1.5 TeV and luminosity $10^{34}\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}$. In the JLC, the beam can not be used again after the collision, so an intense beam has to be generated. As is shown in Fig.1, the design requires 20 bunches with the spacing of 1.4 ns generated in an RF pulse with a repetition rate of 150 Hz. Each bunch should contain 2×10^{10} electrons. The rms normalized emittance should be less than 1×10^{-3} rad•m at the entrance of the damping ring.

There exist two techniques to realize the above beam. One is the conventional thermionic gun using a fast grid pulser and sub-harmonic bunchers (SHB)[2]. The other is an RF gun, of which there are two types. (a) RF gun with thermionic cathode, and (b) RF gun with photocathode triggered by pulsed laser light. We decided to start the development of the RF gun of type (b) at S-band, keeping in mind the characteristics as listed bellow.

(1) The accelerating gradient achievable RF field is much higher than that for a DC or pulsed field, which makes it possible to generate an extremely low emittance beam.

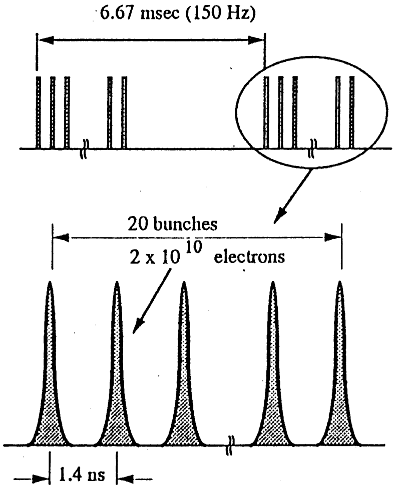

Fig.1 Bunch structure of the JLC

(2) Since the photocathode is triggered with a pulsed laser, pulsed beam can be produced directly on the cathode without using any SHB system. Therefore, it is easier to generate the beam for JLC using a mode-locked laser and/or a mirror multiplexer.

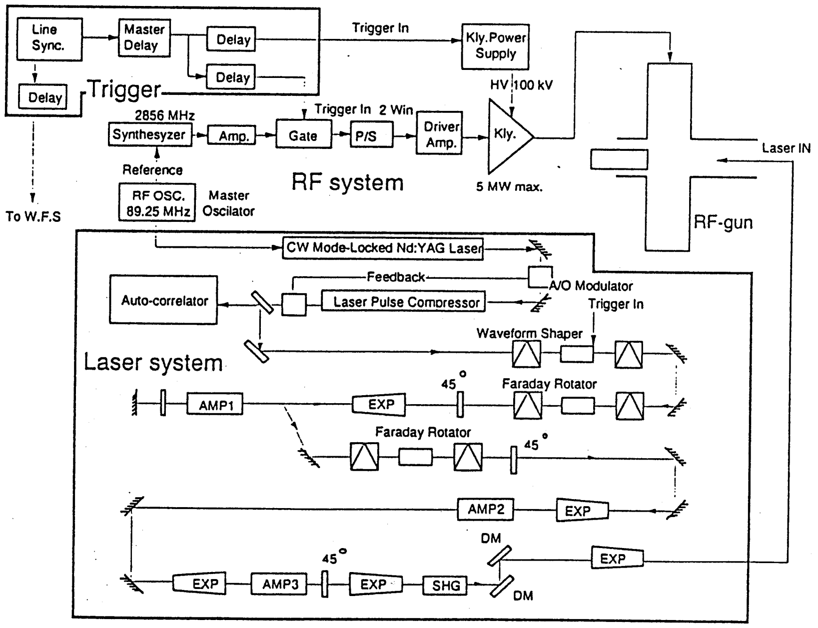

Fig.2 The block diagram of RF gun using laser tiriggered photocathode

(3) Higher current density can be generated from the photocathode than the thermionic cathode. In the Lasertron experiment at KEK, using GaAs photocathode, the current density of 60 A/cm^2 was obtained[3], and the Los Alamos group demonstrated that a current density in excess of 100 A/cm^2 could be obtained with Cs_3Sb photocathode[4]. Given this performance one may expect that the photocathode will satisfy JLC requirements.

On the other hand, there are several hurdles to be overcome for the practical use of the RF gun. (a) The stable laser system is required, which can generate high power of order 1 mJ per pulse in a short pulse of order 1-10 ps. (b) A high power RF system is needed for the high gradient acceleration. (c) Photocathode is required with a long lifetime and a high quantum efficiency (Q.E.), which is coexisted with the large RF fields and the high power laser beam. (d) The low level RF system is needed , which makes it possible to synchronize precisely the laser pulse with RF fields. (e) The beam diagnostics and the simulation of the beam motion are required to understand the beam dynamics.

As a first step of the study of features (a)-(e) we have constructed an experimental facility as shown in Fig.2, centered around an accelerating cavity of a simple half-cell pillbox type. In this report we describe the preliminary results of our experimental and numerical studies.

Experimental apparatus

High Power RF system

The RF source is a pulsed klystron with the peak power of 5 MW, the frequency of 2856MHz and the pulse width of 2 μs. The cavity cross-section is depicted in Fig.3, with parameters as in Table 1. To insure that the cathode rod contacts stably with the cavity wall and that multipactoring must be avoided, we employed the mechanical contact by spring action instead of the choke structure[5]. The cavity is tuned by adjusting the position of the cathode rod. The relation between the resonant frequency and the position of the cathode rod is 9 MHz/mm, permitting a practical range of tuning.

The applied accelerating gradient is desired to be as high as possible to generate a low emittance and high current beam. However high electric field may induce the discharge or multipactor, which deteriorate the vacuum and decrease the lifetime of the photocathode. As a compromise between these two requirements we have set an accelerating gradient of 40 MV/m as an initial target. The cavity has been processed up to the input power of 1.2 MW, the pulse width of 1 μs and the accelerating gradient of 50 MV/m.

Resonant Frequency	2856 MHz
unloaded Q	7592
loaded Q	4348
coupling	Iris type
shunt impedance (SUPERFISH)	33 MΩ/m
Ep/Eacc (SUPERFISH)	1.29

Table 1 parameters of the cavity

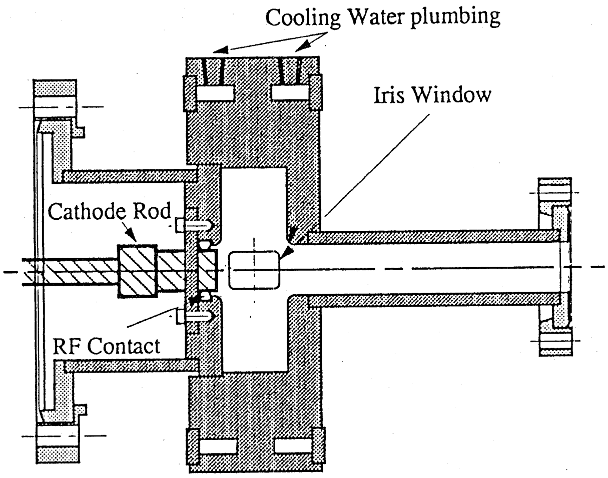

Fig.3 Cross-sectional drawing of the cavity

Low level RF and trigger control

As shown in Fig.2, the master oscillator of the entire system is a 89.25 MHz synthesizer, which is used as a driver of the mode-locked laser. The input signal of the klystron is generated with a 2856MHz synthesizer. After pulse modulation with a pin-diode, the 2856 MHz signal is amplified with the solid-state 600 W amplifier. In the RF gun, the phase between the laser pulse and the RF signal must be synchronized precisely. These two synthesizers share the same 10 MHz time base and are synchronized with each other. However this system has a jitter of about 20 ps/min and the large long term drift, neither of which is acceptably small. We plan to improve this system by using one signal generator, 2856MHz synthesizer, and generate 89.25MHz signal with a frequency down-converter.

The trigger signal is generated with a line synchronization and is fed to each component via delay module. At the first step of the experiment, the klystron is driven at 20 Hz, and the laser at 1 Hz, or in single shot mode.

Laser system

The laser system developed for the Lasertron[3] was remodeled for the present experiment. The oscillator of the laser is a CW mode-locked Nd:YAG laser with the wavelength of 1064 nm, a power level of 4 W and the mode-locked frequency of 178.5 MHz, so that pulse spacing is 5.6 ns. The micropulse width is about 100 ps at the oscillator, and it is compressed to a shorter pulse of about 10 ps with an optical pulse compressor composed of an optical fiber and a grating pair. The laser pulse is chirped by the non-linear optical effect in the fiber and is compressed in time through the grating. A pulse train with a width of 1μs is obtained from the CW laser pulse with the wave form shaper. After that, the pulse is amplified in three amplifiers. Finally, 1064nm wavelength is converted to 532nm with a second harmonics generator (KD*P) and the laser light is guided onto the photocathode in the cavity. The picture of the laser pulse is taken with a streak camera as shown in Fig.5. The energy of the laser is 100 μJ per micro-pulse which is equivalent to 3×10^{14} photons. To satisfy the JLC requirements (2×10^{10} electrons), the Q.E. of the photocathode must be as high as 10^{-3}.

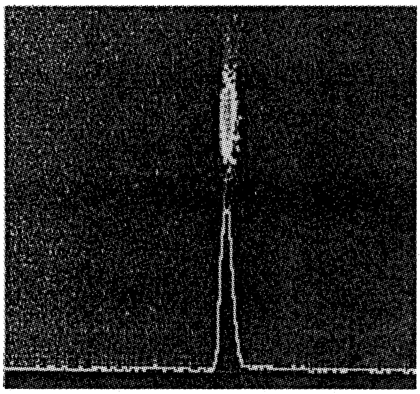

Fig.4 The laser pulse measured with the streak camera FWHM: 12.5 ps

Photocathode

We selected the Sb-multialkali photocathode for the RF gun, as it is widely used for photomultiplier tubes and provides a Q.E. of several percent at the 532 nm wavelength. However in photomultipliers the photocathode is used in a tip-off glass tube, whereas in the present experiment we employed a demountable vacuum chamber. Consequently one may expect larger current and we have carried out various experiments to study this in detail.

The photocathode is activated in a preparation chamber connected to the cavity, avoiding the alkali contamination of the cavity wall. When the photocathode is activated, the preparation chamber is separated from the cavity with a gate valve. The cathode head is mounted on the linear motion, which is guided into the cavity after the activation.

This head can be heated to about 650 °C to clean up the surface. Sb is deposited on the head and the alkali metal is supplied to monitor the photoexcited current at a room temperature. The alkali metal source is the commercially available dispenser type. The time response of the switching of this source is adequate, but the generation of the bad gas can not be suppressed completely. At the moment, the Q.E. is about 10^{-4} and the lifetime is tens of minutes. In the future, the vacuum environment will be improved and higher Q.E. and longer lifetime are expected.

Beam dynamics

The characteristics of the beam in the RF gun are different from the approximately continuous, "steady-state" typical of a DC or pulsed gun. For the RF gun, the effect of time varying fields on a bunched beam are crucial in understanding the dynamics. At the same time, the beam velocity varies over the wide range, from about 0 to the relativistic velocity. In low energy region, the space charge effect is very important, since it is the origin of the emittance growth and debunching. As a first step, we have simulated the beam motion with a 1-D sheet beam model in which the beam is divided into thin sheets. The motion of each sheet is calculated with the relativistic equation of motion in an RF field in the form of $\sin(\omega t + \phi)$ with ϕ the phase at the injection of laser. The results of the 1-D simulation are shown in Fig.6,7 corresponding to an accelerating gradient of 40 MV/m, an initial beam pulse of 10 ps and a beam charge of 6.4nC. In order to reach higher energy and shorter output bunch length, it was found that preferable to set the injection phase of the laser around 0 degree. In future, we will also take account of the transverse motion to estimate the beam emittance more precisely.

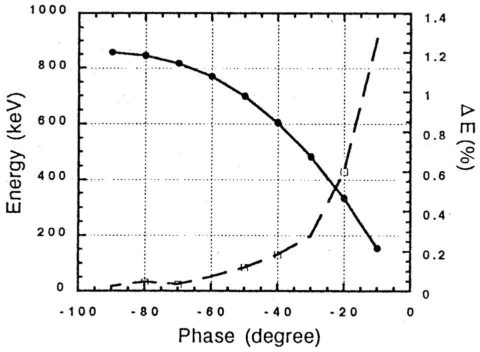

Fig.6 Phase versus energy and energy spread

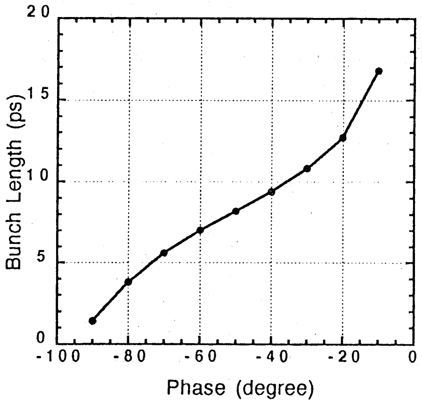

Fig.7 Phase versus bunch length

Summary

At present, we have fabricated and tested all components, including the laser, RF and trigger system. The laser system has already been developed successfully and has a minimum pulse width of the laser is about 10 ps. A fast wall current monitor with the rise time of less than 100ps[6] was mounted to verify that the beam is generated when the laser pulse is synchronized with RF field. The lifetime of the photocathode is not still long enough, but we hope to increase this to tens of hours and Q.E. to more than 0.1% as we continue experiments on the photocathode with test chamber. After that, we will try to test the general operation of the whole system. In parallel, we are preparing the diagnostic system, with which the beam energy, bunch length and beam emittance are measured.

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[1] S. Takeda, presented at this symposium.

[2] T. Naito, presented at this symposium

[3] M. Yoshioka, JJAP, Vol.28, No. 6, June 1989, pp.1079-1093

[4] J.S. Fraser *et al.*, 1987 Particle Accelerator Conf., Wash., D.C., March 16-19,1987

[5] R. Bossart, private communications

[6] T. Naito, presented at this symposium