

INJECTION SYSTEM FOR THE JAERI FEL

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Abstract

The injection system of the JAERI superconducting linac for far infrared FEL oscillation was installed and commissioning operation was started. The characteristics of the electron beam measured, so far, are as follows: The electron beam of 100 mA with 4 nsec bunch length was extracted from the gun at the accelerating voltage of 180 ~ 220 kV. Beam was compressed tentatively to less than 70 psec at the end of transport line by preliminary operation of both the sub-harmonic buncher and buncher.

Introduction

Construction of a superconducting linac driven FEL system for far infrared oscillation has been continued at JAERI and the injection system was installed. An outline of the JAERI FEL program has been reported elsewhere^{1,2,3}. The injection system consists of a thermionic cathode electron gun with a grid structure, a sub-harmonic buncher(SHB), a buncher, and a beam transport line with focusing coils as shown in Fig.1.

The characteristics of the injection system such as the emission current and the bunch structure were measured under the operation of the SHB and buncher. The RF power was supplied into the SHB and buncher by all-solid-state amplifier. The characteristics of the RF amplifier such as baseline power output and phase response data were also measured.

In this article, the status of the injection system for the JAERI FEL is described briefly.

JAERI FEL injection system

The electron gun produces maximum 250 keV electron beam with 4 nsec bunch length at the repetition rate of 10.4 MHz during a macro pulse of 1 msec length at the repetition rate of 10 Hz.

The electron beam is compressed by the SHB and buncher. The SHB is a $\lambda/4$ co-axial type cavity, whose frequency is 83.3 MHz, 1/6th of the main accelerating frequency 499.8 MHz. The gap voltage is 50 ~ 60 kV. The buncher is a re-entrant type cavity of 499.8 MHz. The gap voltage is 5 ~ 10 kV.

The beam is accelerated by the pre-accelerators and main accelerators, which follow the injection system, up to 13.2 MeV or over with ~40 psec bunch length and ~10 A peak current. The time synchronism of the electron gun, SHB, buncher, and superconducting accelerators is made by a master oscillator of 10.4 MHz and its multiplied frequencies.

Electron gun operation

Beam trace calculations are reported elsewhere⁴. The higher electron gun voltage of 250kV than that of usual electron linacs is chosen to reduce the growth of beam emittance by space charge effect during the transportation from the gun to the pre-accelerators through the SHB and buncher. A wehnelt electrode of 4 mm diameter aperture reduces the cathode diameter to realize such low emittance as 10 π mm mrad because a conventional gridded thermionic cathode of EIMAC Y646B has 8 mm diameter. The beam emission is controlled by the grid pulser which forms pulse train of 4 nsec width and ≤ 200 V height with 10.4 MHz repetition rate.

The beam emission is measured by a fast Faraday cup and an amorphous current core monitor at the exit of the gun. The shape of each pulse is almost same. The measured current pulse by the amorphous current core monitor is shown in Fig.2. A measured FWHM value of the bunch length is 4 nsec in the case of 200 kV gun voltage, 100 mA peak current.

All-solid-state RF power amplifier

The linac is operated with pulse mode of 1~2 msec macro pulse and 10 Hz repetition rate. The duty factor is 1~2 %.

The linac consists of the SHB, buncher, 2 modules of the single-cell superconducting pre-accelerator and 2 modules of the 5-cell superconducting main accelerator.

The SHB and buncher are normal conducting cavities, which are used to modulate the beam velocity, and to compress the bunch length. There is no mean acceleration through the SHB and buncher, so the RF power supplies are relatively small. The superconducting accelerators are designed to accelerate the beam to 13.2MeV or over. The low power loss on the superconducting cavity wall reduces the output power of the RF supply. So-called all-solid-state

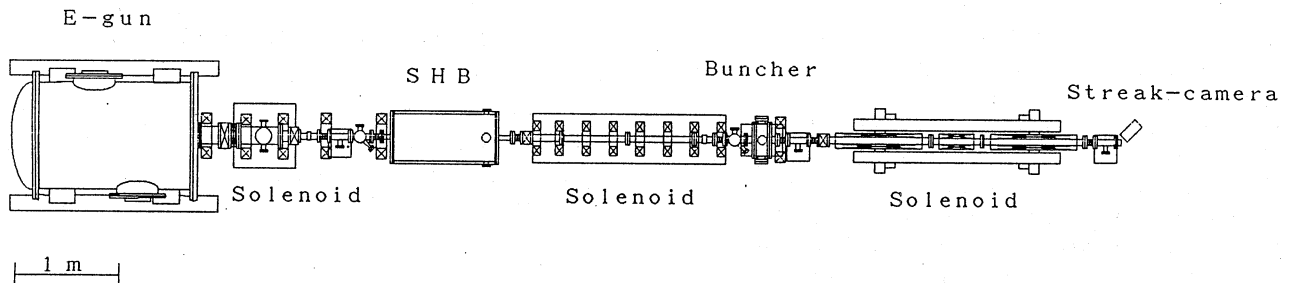


Fig.1 Schematic layout of the injection system of the JAERI FEL facility.

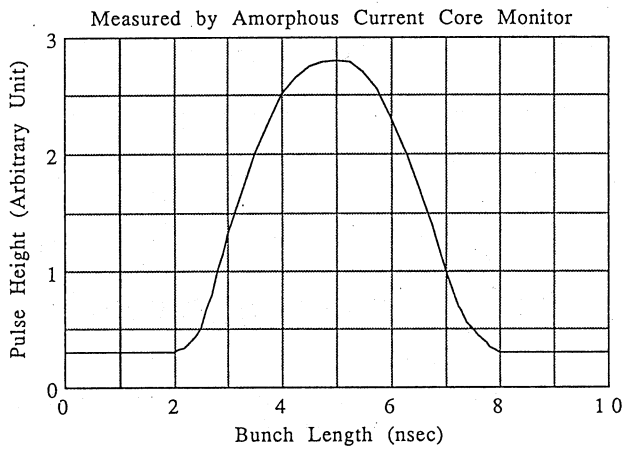


Fig.2 Current pulse measured at the exit of the gun by an amorphous current core monitor.

amplifiers are available for the RF power supplies to feed into all the accelerating cavities.

The merits of all-solid-state amplifier are

- 1) unnecessary of high voltage power supply — free from dangerous apparatus.
- 2) high reliability — easy maintenance.
- 3) redundancy — using transistors excessively, the system maintains the essential RF power level in case of failures of a few number of transistors.

The output power of 83 MHz band RF amplifier for SHB is 5 kW. This amplifier is made up of modules which deliver about 1 kW peak power and 6 modules are combined to develop the final output power. According to the 500 MHz band RF amplifier for the buncher, 5 sets of 330 W amplifier module are combined to develop 1.5 kW peak power.

The RF amplifier was initially tested into a resistive load to establish baseline power output and phase-response data. A phase bridge using a double-balanced mixer was connected between the input of the phase-amplitude controller and the output of the RF power amplifier for phase measurements as shown in Fig.3. Fig.4 shows the RF amplifier output power and phase response. The phase shift and amplifier drop during the 1 msec macro pulse are ~ 8 deg and 2.6 % respectively.

Beam compression test

In the transportation through the SHB and buncher, the beam of 4 nsec bunch length from the cathode must be compressed to several tens pico seconds at the entrance of the pre-accelerator by the following reasons;

- 1) The 4 nsec bunch length from the electron gun corresponds to about 720 degrees of phase spread of 499.8 MHz main frequency. To obtain the beam of energy spread less than 0.5%, the bunch length must be compressed to less than 7 degrees phase spread of main frequency.

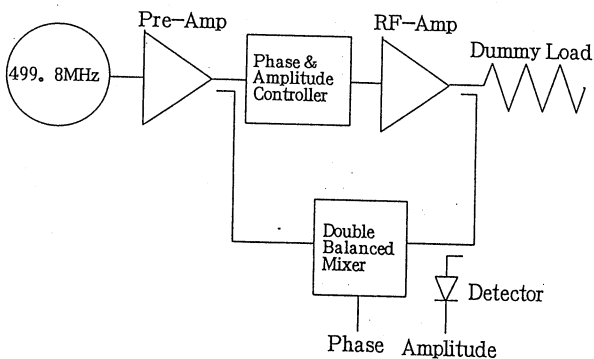


Fig.3 Block diagram of RF amplifier test setup.

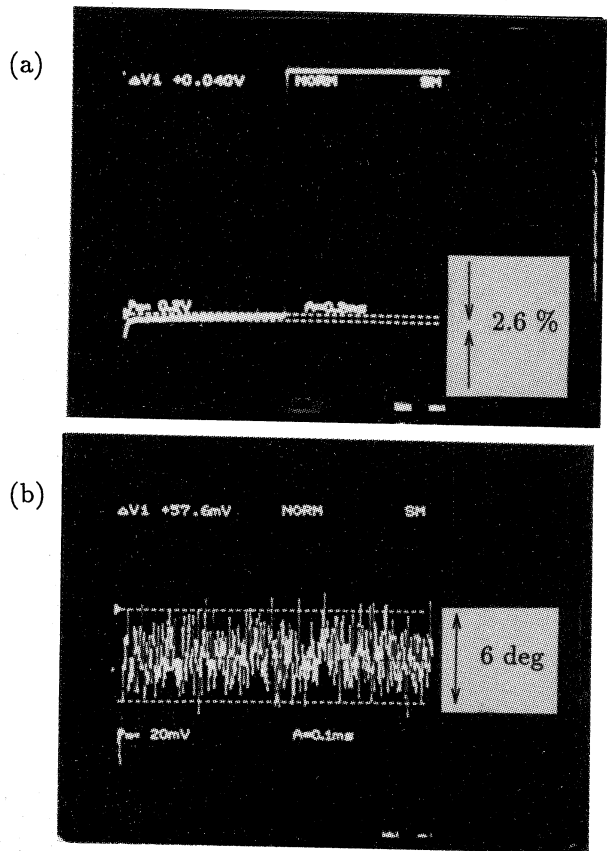


Fig.4 (a) output power.
(b) phase response.

- 2) A gain of FEL oscillation is proportional to the peak current. In the use of conventional electron gun with the thermionic cathode, the peak current is as high as a few hundreds milli-ampere at 2~4 mm beam diameter. To realize the high peak current and high FEL oscillation gain, the bunch length must be compressed to be about 1/100.

The bunch length is compressed in the use of the SHB and buncher by optimizing the amplitude and phase of electric field. The phase of electric field in the SHB corresponds to the bunching, while that in the buncher to the debunching. Because of the sinusously alternating RF field, the electric field in the SHB is not strong enough at the end of the bunch to compress the bunch length. The field of the buncher, which is installed near middle of the drift space, corrects the velocity modulation by decreasing the velocity of the middle of the compressing bunch and increasing that of the end. The result of the simulation using PARMELA code is shown in Fig.5, which indicates that the phase spread is compressed to ~ 8 degrees and that the peak current increases ~ 90 times.

The bunch length was measured by adjusting the phase and amplitude of the RF power fed into the SHB and buncher. In order to measure a short bunch length less than a hundred psec, the electron beam was converted into a Cherenkov radiation by a sapphire glass plate situated at the end of the beam line. The radiation was detected by a streak camera made by Hamamatsu Photonics Co. Fig.6 shows the Cherenkov radiation measured by the streak camera, which corresponds to 70-psec bunch length.

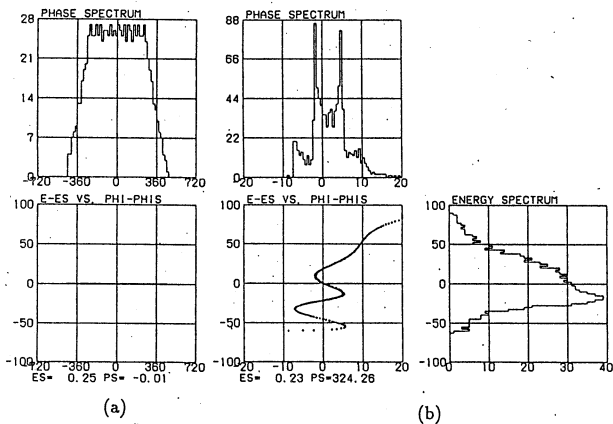


Fig.5 Simulation results of beam compression calculated by PARMELA code.

- (a) Initial longitudinal phase space and phase spectrum.
- (b) Longitudinal phase space at the end of transport line and phase and energy spectrum.

The units are deg and keV for phase and energy. Phase corresponds to main frequency of 499.8 MHz.

Conclusion

The compressed electron beam less than 70 psec is achieved. The RF system was not stable enough to get shorter bunch length up to now. Improvement of the RF system is expected to bring shorter bunch length. High current beam such as 100 mA will expand the bunch length and induce the emittance growth as compressing the beam. So it is necessary to measure the emittance at the end of the transport line.

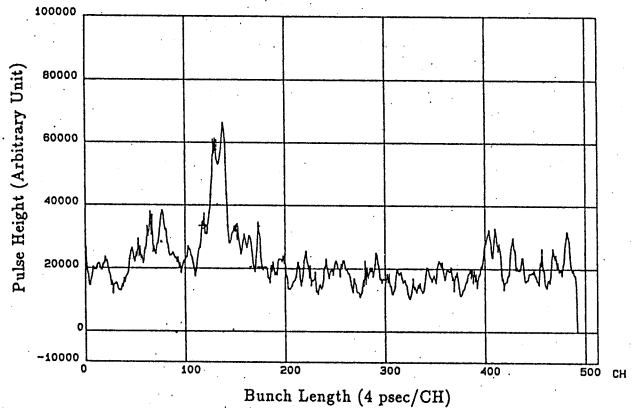


Fig.6 Measured bunch length at the end of transport line by a streak camera.

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