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DEVELOPMENT OF A COMPACT LINAC FOR FEL OSCILLATION

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Abstract

We developed a compact linac as both an injector for synchrotron radiation (SR) ring and an electron source for free electron laser (FEL). The linac has a high accelerating gradient of 22MeV/m and is very compact. Recently, we proceeded with studies on FEL using this linac. The beam acceleration of 10μs macropulse duration at 50MeV was achieved and energy spread and peak current were 0.6% and 28A, respectively.

1. Introduction

Recently, it gets much attention that synchrotron SR light has potential for the industrial applications, thus a compact SR machine has been awaited. We have continued our R&D efforts to develop compact SR machines. The SR machine consists of a linac and an SR ring. Both of them require compact design. We first launched the development of a compact SR ring (NIJI-III) using superconducting magnets. It has already completed in 1991.

For the linac, we completed the development of a compact linac by ourselves in 1993 (Fig.1) and achieved the electron beam acceleration at 100MeV-100mA in July 1994. The compact linac has two special features. One is a high accelerating gradient (22MeV/m) and another one is the two mode accelerating (SR and FEL mode).

Recently, we proceeded with studies on FEL using our linac[1][2]. On this paper, the beam characteristics of our linac and the experimental results of FEL are described.

2. Compact linac for FEL oscillation

Since very severe qualities of electron beam, described as follows, are needed for FEL oscillation, we make some efforts in our linac.

(1)long macropulse duration
(2)narrow energy spread
(3)low emittance
(4)high peak current

We aim for FEL oscillation in an infra-red region. In order to obtain small signal gain of 10%, the peak current of 25A and the energy spread of 0.6% are necessary. The gain was calculated in accordance with the reference of [3]. Experimental conditions are summarized in Table I [1].

Table I. Experimental conditions of FEL

Beam energy	50MeV
Energy spread	0.6%
Peak current	25A
FEL wavelength	2.8μm
Gain	10%

2-1. Long macropulse duration

When we discussed the macropulse duration of the electron beam for FEL experiments, the results of FELIX [4] was referred. As the intensity of FEL saturates after 3μs or so from the pulse rising of the beam, the macropulse duration of more than 10μs is necessary for the infra-red FEL oscillation.

A klystron used in our linac is the TH 2146 by Thomson Tubes Electroniques. It is capable of producing the two different microwaves of 1μs duration (45MW) to inject the SR-ring and of 10μs (22.5MW) for FEL. The mode of SR/FEL can be changed automatically.

2-2. Narrow energy spread

In order to achieve the energy spread of 0.6%, we attempted to stabilize the temperature of an accelerating tube and the output voltage of a klystron modulator.

Temperature variation of the accelerating tube causes thermal expansion/compression of the oxygen-free copper, the major structural material for the accelerating tube, and causes the resonance frequency to shift by approximately 50 kHz / ℃. Since the accelerating tube has a quite high Q of 12,500, even a slight shift of resonance frequency can cause impedance mismatching, and the microwave power that can be injected into the accelerating tube is consequently reduced. As a result, beam energy varies. To further narrow the energy spread, the temperature stability of the cooling water must be improved. Some time ago we developed a high-precision cooling water system for optical fiber testing. For the present study we developed, with assistance from Sumitomo Densetsu Co., Ltd., a cooling water system with a very high temperature stability of less than ±0.02℃. With conventional cooling water systems, the beam energy spread caused by temperature variation of the accelerating tube is 0.7%, whereas it is below 0.1% with the our cooling water system.

Suppressing beam energy fluctuation requires stable output pulse voltage for the klystron modulator. A high-stability klystron modulator was developed with cooperation from Nissin Electric Co., Ltd. The klystron demands a high-power driving pulse with a voltage of 305 kV and current of 340 A (short pulse mode). The klystron modulator has several features as follows:

1)PFN (Pulse Forming Network) consisting of parallel networks of 21 capacitors and 21 reactors
2)capacitors with very low self inductance (<100nH)
3)stepping motors to simplify a reactance adjustment of the PFN circuit

The output voltage stability of less than 0.3% was achieved as shown in Fig.2.

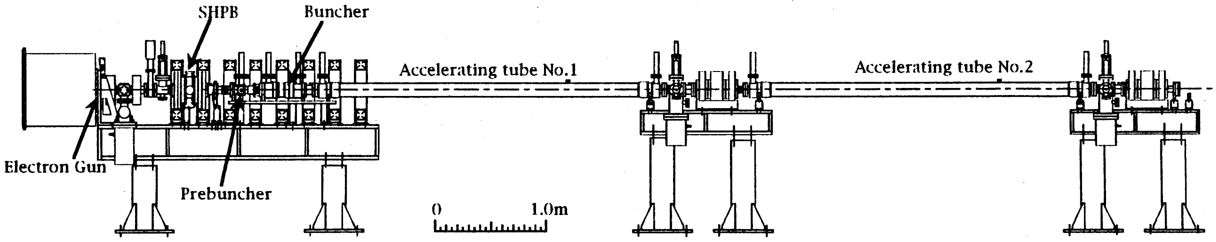


Fig.1. Compact linac for FEL oscillation

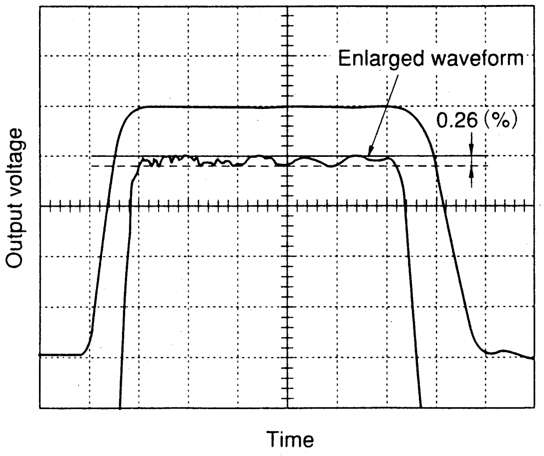


Fig.2. Pulsed voltage waveform of the klystron modulator (ordinate : 44kV/div, abscissa : 2μs/div)

2-3. Low emittance

The electron gun is a thermionic triode gun based on a dispenser cathode assembly (EIMAC model Y646B). A high D.C. voltage of 200KV is applied to anode-cathode gap to obtain low emittance. The shapes of the electrodes were optimized through simulations. A normalized emittance of 7π mmmrad and beam current of 1.5A were obtained in the electron gun testing.

2-4. High peak current

To achieve high peak current (25A), an SHPB system (an SHPB cavity and a 476MHz rf amplifier) was installed in the compact linac. The SHPB is a standing-wave cavity with a resonance frequency of 476MHz. Short filling time and high shunt impedance are necessary to reduction of the rf amplifier load. In order to optimize both Q-value and shunt impedance of the cavity, a portion of the inner surface of the cavity was coated by OFHC.

To supply rf signals to the SR ring (158.6MHz) and the grid pulsar of the burst-mode electron gun (79.3MHz), we chose a frequency multiplier system which can generate the microwaves of 79.3, 158.6, 476, 2856MHz. In general the lowest frequency is chosen as a fundamental one. On the other hand, the frequency stability for acceleration (2856MHz) is most important. In consideration of the frequency-limitation of IC-counter, the harmonic relation of four microwaves, the results of KEK and so on, we chose 467MHz as the fundamental frequency. The rf power amplifier for the SHPB is all-solid-state one and its maximum rf output power is 4.6kW.

The electron beam emitted from a cathode is focused by the focusing electric field of the Wehnelt-anode gap. Also the beam is defocused by the space charge effects in the bunching section. Thus, according to the increase of electron density, the beam focusing of the solenoid is changed.

An ideal magnetic field of nine helmholtz coils arranged along the bunching section is given by Kapchinsky-Vladimirsky equation[1]. If electron beam energy is lower than 5MeV, using the V-K equation, the magnetic field Bs to fix a radius of an electron beam can be calculated from:

$$Bs(T) = 3.69\times10^{-5}\sqrt{I(A)/\beta\gamma}\ /r(m)$$

where I is peak current of electron beam, r is beam radius, β=v/c ,and γ is Lorentz factor.

The longitudinal magnetic field distribution along the bunching system at present is shown in Fig.3. The field optimized at the experiment is identical with the calculation.

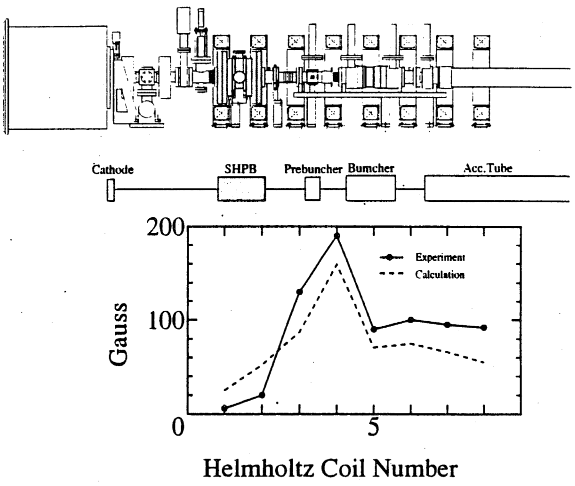


Fig.3. The longitudinal magnetic field distribution

3. Experimental results and discussion

3-1. Measurements of micropulse shape

The SHPB is effective for the increase of the peak current. So it is important to understand the characteristics of the SHPB.

In order to measure a micropulse shape of the electron beam, Cherenkov radiation which electron beams emit in air are detected by the bi-planar phototube (HAMAMATSU PHOTONICS : R-1328U-02 ; Rise time : 60ps). The measurement set-up of Cherenkov radiation is schematically depicted in Fig.4. A wire monitor (secondary-emission monitor) was installed to the end of the beam line to obtain a characteristic of the micropulse shape.

We measured the bunching ratio for various rf power outputs to obtain optimized rf power of SHPB. The bunching ratio was obtained by the ratio to a pulse height at bunched beam to non-bunched one that measured by the bi-planar phototube or a wire monitor. The rf power dependence of bunching ratio is shown in Fig.5. When the rf power was optimized (about 3kW), the peak current increased from 6A to 28A. The pulse shape of the beam bunched at 476MHz is shown in Fig.6. The transformation of micropulse shape for various rf phases is shown in Fig.7. These behaviors can be explained that the rf phase and power to the SHPB cavity was optimized.

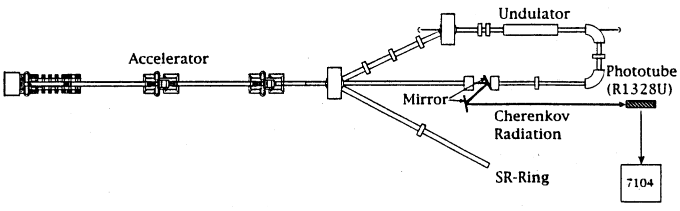


Fig.4. Optical guiding and measurement system of Cherenkov radiation

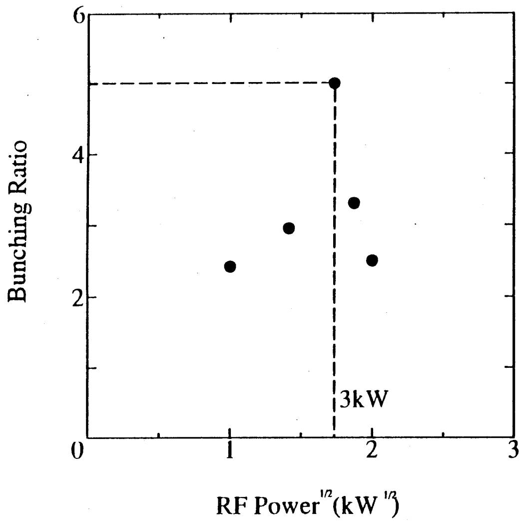


Fig.5. Rf power dependence of bunching ratio

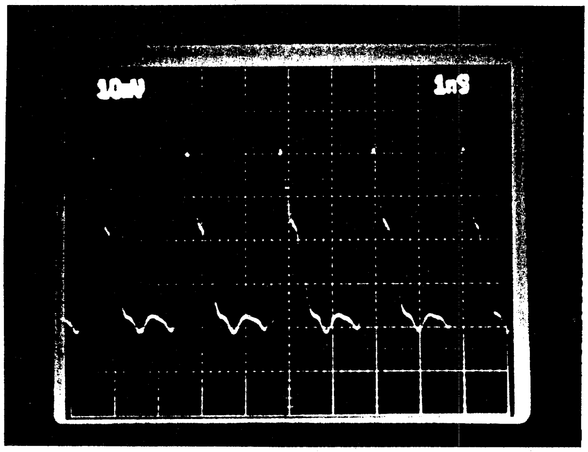
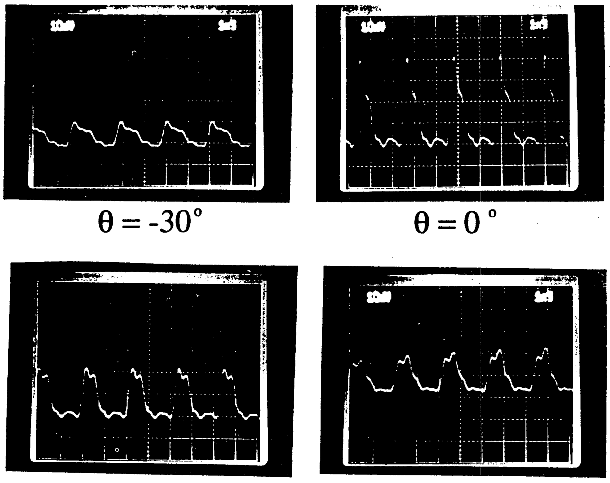


Fig.6. Micropulse shape
(abscissa : 1ns/div)



$\theta = -30°$ $\theta = 0°$

$\theta = -10°$ $\theta = +20°$

Fig.7. Rf phase dependence of the micropulse
(abscissa : 1ns/div)

3-2. Energy spread measurement

Small signal gain depends on the energy spread of the beam. The energy spectrum at 50MeV is shown in Fig.8. The energy spread (FWHM) of 0.6% was achieved.

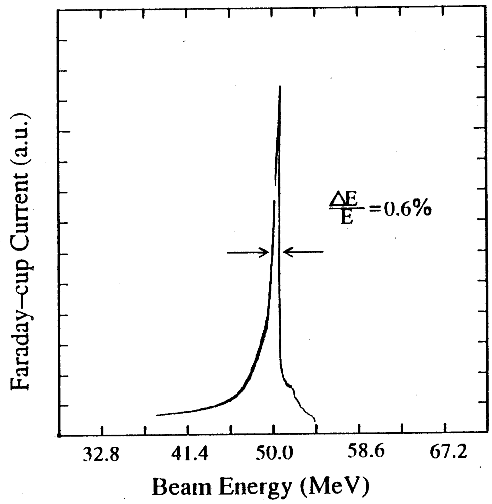


Fig.8. Energy spread at 50MeV

4. Conclusions

We have developed the compact linac as both the injector for NIJI-III and the electron source for FEL oscillation. The accelerator tube cooling system with high temperature stability and the klystron modulator with a output pulse voltage stability of less than 0.3% help the achievement of narrow energy spread and the stable micropulse cycle. As a result, the acceleration of 50MeV with energy spread of 0.6% was achieved.

The SHPB system was installed and we tested its performance. As a result,the SHPB system was successfully operated and the peak current increased from 6A to 28A .

We achieved the experimental condition of FEL. Also we intend to accomplish FEL oscillation .

Acknowledgements

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References

[1]K.Emura et al.,Proceedings of The 20th Linear Accelerator Meeting in Japan. (1995) 63
[2]T.Shinzato et al.,in this symp.
[3]P.W.van Amerdfoort et al., The FELIX project status report April 1988,Rijnhuizen Report 88-176
[4]B.J.Bakker,"Free electrons as a versatile source of coherent radiation." Doctoral Thesis in FELIX 1993.
[5] T.Tomimasu et al., Introductory Book on Free Electron Laser . (1995) 103. (Atomic Energy Society of Japan)