PERFORMANCE OF THE FEL LINAC AT NIHON UNIVERSITY

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Abstract

The construction of the 125 MeV linac was completed in 1997. After aging of rf components, i.e. klystrons, wave guides and accelerating tubes, and improving of defects in the power supplies, the beam acceleration test of the linac has been performed since December of 1997. The first spontaneous emission in the FEL undulator was observed in February of 1998 using the 80 MeV electron beam from the linac.

1 INTRODUCTION

The design and construction of the 125 MeV linac at Nihon University was started in 1994 under the cooperation of KEK, PNC, ETL and Tohoku University [1]. The main purpose of the linac has been the oscillation of the free electron laser (FEL) and study of its application. The construction was completed in the spring of 1997, and soon the operation of the high power rf system was started[2]. After conditioning of the rf system and preparation of the dc electron gun system, the beam acceleration test was started in December of 1997.

Fig. 1 shows the bird’s-eye view of the experimental facility, Laboratory of Electron Beam Research and Application, in Funabashi campus of Nihon University.

Table 1: Design parameters of the 125 MeV linac.

Maximum electron energy	125	MeV
Rf frequency	2856	MHz
Number of klystrons	2	
Maximum peak rf power	60	MW
Modulator pulse length	30	μs
Maximum beam macropulse length	20	μs
Pulse repetition rate	12.5	Hz
Macropulse peak current	200	mA
Micropulse peak current	20	A
Micropulse length	3.5	ps
Normalized emittance (rf gun)	$< 20\pi$	mm·mr
Energy spread (FWHM)	0.5	%

The design parameters of the linac are listed in Table 1. The oscillation of the FEL can be achieved with the high current density, high brightness, and relatively long macropulse electron beam. Also a high stability of the operation of the linac is necessary for a stable oscillation, i.e. the stability of the rf power, the rf phase and the beam current are very important factors for a successful operation. A part of the parameters listed in the Table 1, the maximum rf power, the maximum electron energy and the emittance of the beam, will be realized after some improvement of the accelerating system in the near future.

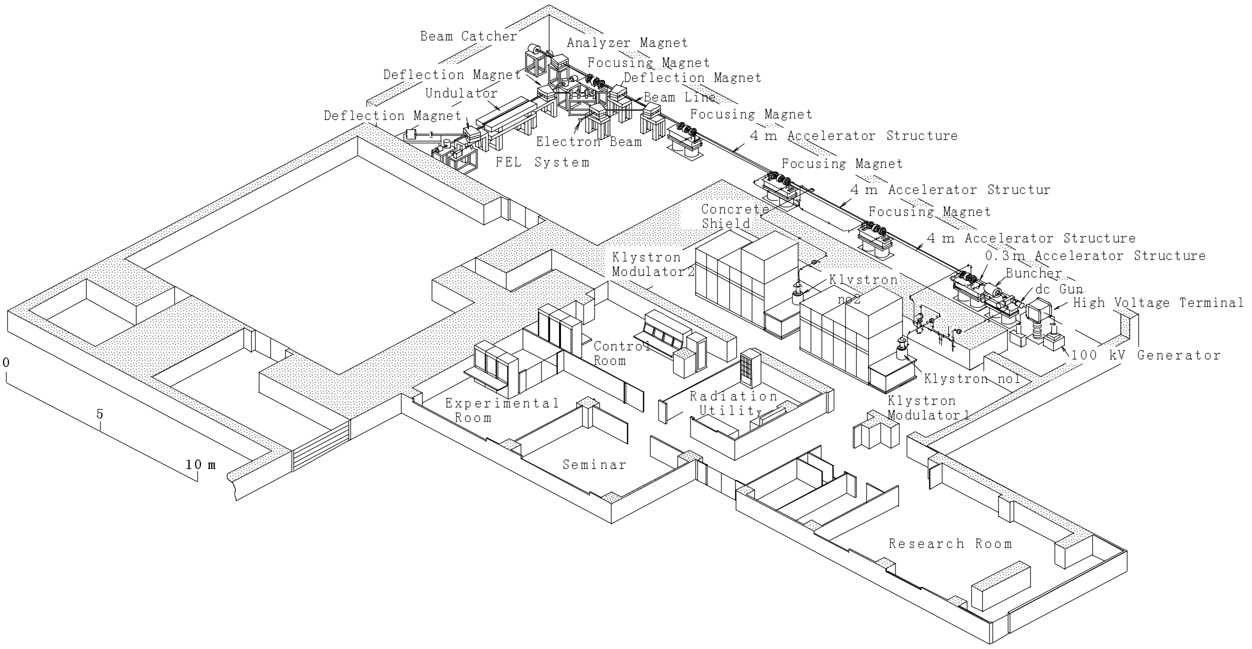

Fig. 1: Bird’s-eye view of the experimental facility in the building of Laboratory of Electron Beam Research and Application located in Funabashi campus of Nihon University.

In this paper the preliminary result of the beam acceleration is reported together with the beam handling and a brief observation of the undulator radiation.

2 OPERATION OF THE LINAC

2.1 *Aging of the klystrons*

Since the present linac was designed to be operated with a relatively long pulse and a high rf power, the aging of the klystrons was performed carefully. After aging more than 100hrs for each PV3030 type klystron[3], already worked for a long time for KEK-PF linac, the peak output power of around 20MW from each klystron was achieved with the rf pulse length of 20μs, although the guaranteed pulse length is less than 5μs at 30MW output.

Also the aging of all the wave guides and the acceleration tubes was performed simultaneously. The regular $\beta=1$ accelerating section composed of three 4m tubes was moved from KEK-PF positron linac.

The test of the klystron pulse modulator with a diode mode klystron load was performed at the repetition rate up to 12.5Hz. But the rf output test and the aging of the rf system have been restricted to 2Hz, in order to avoid a possible damage to the rf windows at the early stage of the operation.

2.2 *The high power rf system*

The electron beam is accelerated in a 30cm $\pi/2$ mode traveling wave tube and three $2/3\pi$ mode 4m traveling wave tubes after bunched with a prebuncher and a buncher. The 30cm tube was placed assuming a pre-acceleration of the low energy beam so that the large phase slip in the first 4m tube can be reduced considerably, especially in the case of the rf gun configuration.

The 1/4 of the rf power from the klystron #1 is supplied to the prebuncher-buncher system by using of a 6dB directional coupler. The remaining power is supplied to the 30cm tube. The power passed through the 30cm tube is again supplied to the first 4m tube. The rf phase in the 4m tube is adjusted with a high power phase shifter at the entrance of the tube.

The power from the klystron #2 is divided into half, then supplied to two 4m tubes separately. The rf phase relation between the two tubes is fixed by the length of the wave guides. Therefore no phase shifter is used, which is the same as the regular section of KEK-PF linac.

The combination of the high speed phase shifter & attenuator and the 800W pulsed rf amplifier, used to drive the klystron, allows fast control of the power and the phase of the rf supplied to the klystron. This system can be used to reduce the fluctuation of the power and the phase in the duration of the rf pulse, though no feedback control is made in the present operation.

2.3 *Use of the dc electron gun system*

The early design of the linac assumed the use of a thermal cathode rf electron gun which has been expected to offer a high brightness, high current density, narrow energy spread, and well bunched electron beam when combined with an alpha-magnet system. However, a strong effect of a back bombarding caused by electrons decelerated in the rf gun cavity will result in a rapid increase of the beam current in the duration of the long macropulse[4]. This phenomenon will be a critical problem when used for the FEL experiment. A photo-cathode rf gun may be the best choice in the future system.

In the present operation of the linac, the use of a conventional dc electron gun is one of practical solutions for the progress of the FEL project because of simplicity and reliability.

The dc gun housing and the cathode assembly, EIMAC Y646E, were prepared by KEK. The 100kV dc power supply and the high voltage terminal with the gun controller, once used for the double-sided microtron[5], were improved to fit the new cathode and the high current pulse operation. The remote gun control and monitor system, where a serial communication is made via the optical fiber cables, has come to be available with a minor improvement.

2.4 *Beam acceleration test*

The beam test has been performed at the repetition rate of 2Hz by the reason mentioned previously.

The energy of the accelerated electron beam has been analyzed with a small 30° bending analyzer magnet placed at the end of the straight beam transport line downstream the linac. A rough observation of the energy spectrum of the deflected beam has been made visibly with a fluorescent beam profile monitor placed at 1m downstream the exit of the bending magnet. At the low current output test, the electron energy greater than 100MeV was achieved.

The three 45° bending magnets for the FEL experiment have been excited accordingly to the evaluation of the beam energy made with the analyzer magnet. Then the beam has been injected into the undulator. The beam passed through the undulator has been stopped in the beam catcher.

Fig. 2 shows an example of the digital oscilloscope view of the macropulse wave forms observed with ferrite core current transformers placed at 1) exit of the 30cm tube, 2) exit of the first 4m tube, 3) exit of the final 4m tube and 4) exit of the final 45° bending magnet, where the momentum acceptance in the 90° bending section was adjusted with the slit to 2% for about 80MeV/c beam.

It looks that about 65% of the beam from the linac has passed through the undulator beam line except for the first a few μs, which may be reasonable taking account of the use of the dc gun and a rather poor stability of the output rf.

The beam pulse length can be adjusted with a variable resistor in the high voltage terminal. At the test as shown in the Fig.2, the pulse length was adjusted to be 10µs.

The inner diameter of the vacuum duct in the undulator is only 7.05mm, and a collimator with a diameter of 6mm has been placed at the entrance of the undulator. But there have been no serious problems for the beam handling.

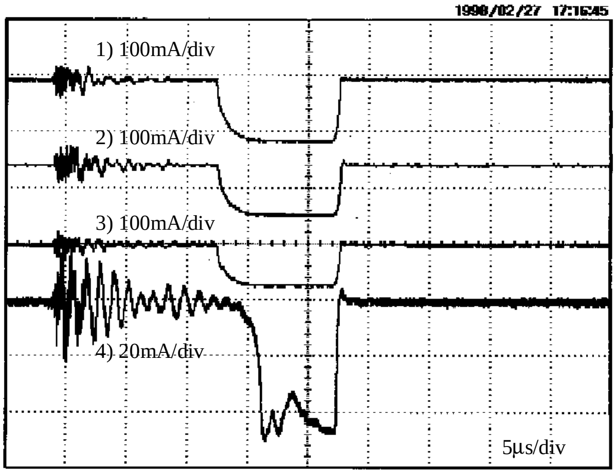

Fig. 2: The beam current wave forms observed at 1) exit of the 30cm tube, 2) exit of the first 4m tube, 3) exit of the final 4m tube and 4) exit of the final 45° bending magnet. The extracted beam with the energy of about 80MeV and the energy spread of 2% was injected into the FEL line. The macropulse length from the gun is 10µs.

3 OBSERVATION OF THE UNDULATOR RADIATION

The parameters of the optical cavity for the FEL experiment are listed in Table 2. The first observation of the spontaneous emission in the undulator was performed at the electron energy of about 80MeV. The light passed through the 488nm narrow band mirror placed downstream the undulator was deflected about 90° toward a telescope on which a color CCD video camera was mounted. Since the exposure of the camera was gated with the machine trigger, the image of the undulator radiation was taken every 15 frames and observed on a TV display. The half mirror placed in front of the narrow band mirror allowed to extract half of the radiation, then the undulator radiation was transported to the telescope placed in the control room with 8 mirrors. Therefore, the radiation was also observed with the eye through the telescope.

Table 2: The parameters of the FEL optical cavity.

Undulator length	2400	mm
Undulator wavelength	24	mm
Number of periods	100	
Undulator gap width (variable)	11~200	mm
K value at gap width 11mm	0.7	
Inner diameter of vacuum ducts	7.05	mm
Optical cavity length	6718	mm
FEL wavelength range	5~0.3	µm

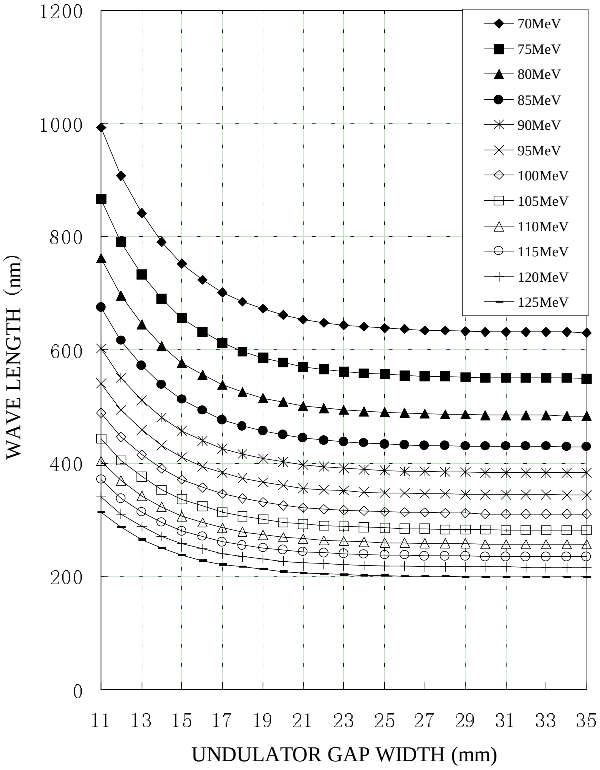

Fig. 3: Dependence of the wavelength of the fundamental undulator radiation on the gap width and the electron energy, deduced from the magnetic field measured at the variety of the gap width.

The undulator gap width is variable at the rate of 1mm/s from 11mm to 200mm. The wavelength of the fundamental radiation depends on the electron energy and the magnetic field (i.e. the gap width) as shown in Fig. 3. During the increase of the gap width from 11mm to 30mm, the color shift of the radiation from red to blue was observed at the electron energy of about 85MeV, which is consistent with the prediction as in Fig. 3.

The electron beam and the intensity of the radiation were quite stable during the change of the gap width.

4 REFERENCES

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