RADIATION FROM THE FEL UNDULATOR AT NIHON UNIVERSITY

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Abstract

The experiments on undulator radiation were carried out at Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University in order to achieve FEL. To take spectra of the undulator radiation a measurement system using a monochromator and a CCD camera has been developed. Spectra obtained by the this system have broader width than that of numerical calculation. Its wavelength tends to shift to shorter side than that expected theoretically. This is considered to be a decrease of the field of the permanent magnet of the undulator due to an intense flex of γ-ray and electron beam.

Introduction

An FEL system which should cover from infrared to ultra violet region was designed and constructed at LEBRA since 1994[1]. The project is its lasing in short wavelength using the linac and application to material and life science as a light source[2]. In 1998 the operation of the linac succeeded in accelerating of 90MeV electron beams[3]. The undulator radiation in visible region was also observed and it was confirmed that the wavelength of the radiation is controlled by the undulator gap.

For realization of FEL at LEBRA it is necessary to investigate the fundamental characteristics of the spontaneous radiation. It is also important for the application studies. Therefore, we have developed a measurement system using a monochromator and a CCD camera in order to measure spectra of the undulator radiation[4]. In this paper the experimental results obtained by the measurement system are reported and discussed.

Linac and Undulator of LEBRA

The electron beam from the linear accelerator passes through the undulator gap and generate radiations. The parameters of the linac and undulator at LEBRA are shown in Table 1.

The maximum energy of the linac is 125MeV and its beam current is 200mA during a macro pulse. Since the light amplification requires a wide beam pulse, it is designed so that its pulse width is 20μs. The peak current and the emittance are relatively excellent as a linac.

Using the linac the betatron oscillation is not a severe problem. To reduce the load of the driving system, the undulator of LEBRA was designed so that the magnet array moves horizontally. This arrangement made change of undulator gap width smoothly.

Since maximum electron energy of linac was 125MeV, the period of the undulator was decided on 24mm in order to oscillate in region from infrared to ultra violet. Because of the difficulty of downsizing an electromagnet, permanent magnets are used for the undulator. As the magnet material NdFeB was chosen in consideration of the field strength.

Table 1 Linac and undulator parameter

Electron linac	
Maximum energy	125MeV
Electron beam intensity	200mA
Pulse width of electron beam	20μs
Bunch length of electron beam	3.5~10ps
Maximum peak current	20A
Repetition rate	12.5pps
Acceleration frequency	2856MHz
Energy spread	0.5%
Normalized emittance	50π mm·mrad
Undulator	
Type of magnet array	Halbach
Undulator period	24mm
Undulator gap	11~30mm
K parameter	1.07~0.086
Number of period	100
Material of magnet	NdFeB

Experiment

The experimental set up for the measurement of the undulator radiation is shown in Fig.1. The spontaneous radiation is extracted from the cavity using a beam splitter mounted downstream the undulator and transported to the control room by several plane mirrors. Total length of the light path is about 30m. The radiation is collected using a telescope and its spectrum is measured.

The measurement system consists of a monochromator with a grating and a CCD camera as an imaging device. The specification of the elements is indicated in Table2. The CCD camera is controlled by a PC through an ISA bus board. The images are processed by a software for MS-Windows to display the spectra. The diagram of the data taking system is shown in Fig.2. To reduce the background the exposure time of the CCD camera should be as short as possible. The exposure time is set as 30ms and its mechanical shutter takes the coincidence with an electron beam pulse using a trigger of a previous beam pulse. The trigger pulse is delayed and inputted into the controller board.

The undulator radiation generated by 87MeV electron beams was measured undulator the condition that K parameter is 1.07. For the adjustment of the measurement aperture, an iris is inserted in front of the telescope. Irises with diameters of 30mm, 50mm and 125mm, which correspond to the collection angles of 1mrad, 1.5mrad and 4mrad respectively, are prepared.

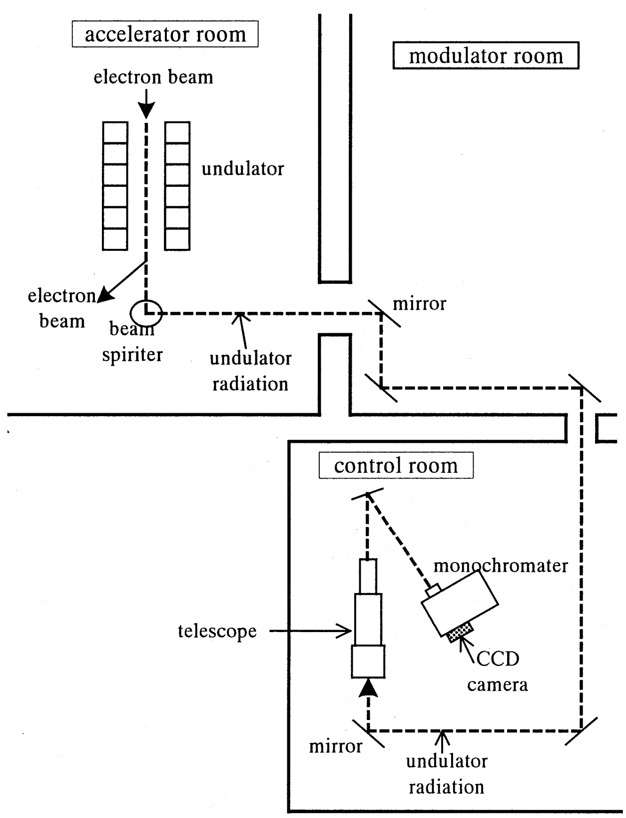


Fig.1 Undulator radiation is extracted from the cavity by beam spliter and transported to the control room and dispersed by monochromator. Spectra of undulator radiation are observed by the CCD camera.

Table 2 Specification of monochromator and CCD camera

Monochromator (Nikon G250)	
Optical type	Czerny-Turner
Reciprocal linear dispersion	6nm/mm
Resolution	0.2nm
CCD camera (Apogee SPH-5)	
CCD array	Hamamatsu S7030-1007
CCD format	1024×122
Pixel size	24μm
Exposure time	0.03~10400sec

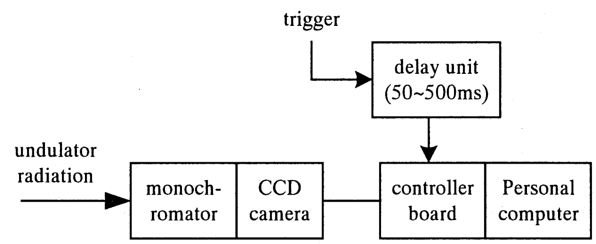


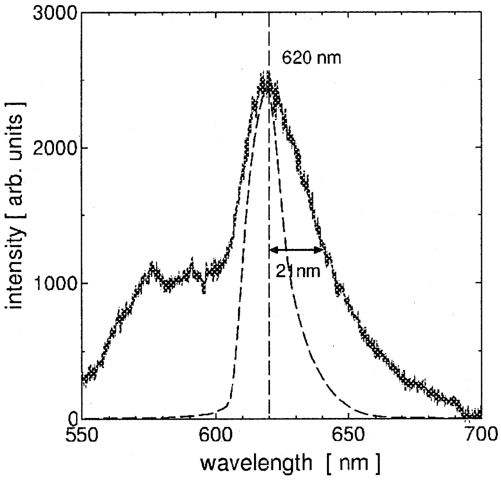
Fig. 2 measurement system diagram

Results and Discussion

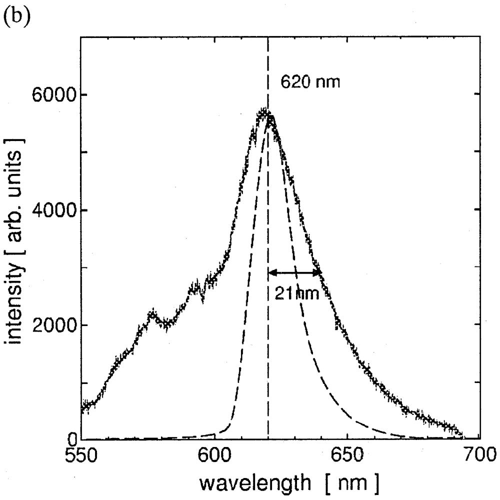
The peak width of each measured spectrum was broader than that of the calculated one. Since the wavelength of the undulator radiation is a function of a radiated angle from the beam axis, the spectrum measured using a telescope depends on the acceptance angle.

In order to estimate this effect experimentally, we measured the spectra using irises of three kind of sizes, that are set in front of the object lens of the telescope. Typical spectra are compared with calculated (broken line) ones in Fig.3. Acceptance angles are 1mrad for Fig.3 (a), 1.5mrad for (b) and 4mrad for(c), respectively. In spite of difference of the peak height, half width of (a) and (b) is the same. It suggests that the monochromator was miss aligned from the electron beam axis about 0.5mrad. The alignment of the monochromator was performed using He-Ne laser. Then the orbit of the electron beam in the undulator might be different from the laser or distorted by the accidental error field. Both spectra, the half width is about twice the calculated ones. The calculations were performed including the electron beam condition[5]. We assumed the electron beam energy of 87MeV, energy spread of 1% and off axis of 0.5mrad with zero emittance. The K parameter of the undulator was assumed to be 1.01. For the spectrum with acceptance angle of 4mrad, the measured half width agrees with the calculated one. It is confirmed correlation

(a)



(b)



(c)

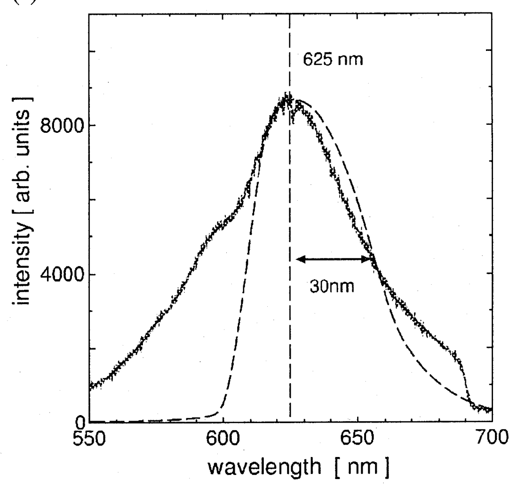


Fig.3 Measured spectra of the undulator radiation (solid lines) and numerical calculation (dashed lines), where electron energy is 87MeV and its spread is 1%. K value of the experiment is 1.07 and that of calculation is assumed as 1.01. Collecting angles for the radiation are (a) 1mrad, (b) 1.5mrad and (c) 4mrad, respectively.

qualitatively between spectrum width and acceptance angle of undulator radiation.

The peak position of the in each spectrum is about 620nm. The expected wavelength is 650nm for the electron beam with energy of 87MeV and the K value of 1.07. This value of the K parameter is deduced from the measured field distribution. There are two reasons for the shift of the wavelength. One is the reduction of the K value due to the decrease of the magnetic field strength or the expansion of the undulator gap. Another is an error of the electron energy about 2MeV lower. The errors of the electron energy and/or gap width are not the reason why the half width of the peak expands into twice of the calculated one. The half width of the peak also depends on the beam emittance and the focusing condition in the undurator. The calculation including the beam quality should be performed.

A satellite or a parasite peak is observed at about 570nm in the every spectrum shown in Fig.3. Because of the characteristics of the monochromator, the peak of a second or higher harmonic can appear in the spectrum near the fundamental. To confirm the effect of the higher harmonics, we have scheduled an experiment with filtering devices. From the recent measurement, the magnetic field strength was found to be decreased due to the radiation damage. The correlation of the field reduction with the deformation of the spectrum is not analysed yet.

References

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[5] Atomic Energy Society of Japan, Introductory Book on Free Electron Laser (1995) p54