ANALYSIS ON VARIATION FACTORS OF OPTICAL POWER AT THE LEBRA FEL[*]

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Abstract

The near-infrared free electron laser (FEL) at the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University has been provided for scientific studies in various fields since 2003. The behaviour of the LEBRA electron linac system has been monitored using various diagnostic devices such as beam position monitors, vacuum gauges, thermocouples, optical power monitors and so on. The results obtained during operation of the linac have been routinely stored in databases or files. This paper discusses about the analysis on the factors of fluctuation for the electron beam energy/position and the FEL optical power on the basis of the linac diagnostic results.

INTRODUCTION

At the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University, a high performance electron linac for generation of Free Electron Laser (FEL) and Parametric X-ray Radiation (PXR) has been studied as a main theme of the joint research conducted with High Energy Accelerator Research Organization (KEK)[1][2].

The linac cooling water system, once used for the 35MeV double sided microtron, was replaced and improved in 2005~2007 due to poor stability of the FEL power resulted from the temperature fluctuation in the cooling water[3]. By this improvement the temperature of the fine cooling water for the accelerating tubes and the magnets has been stabilized to 30±0.01°C, the coarse cooling water for the klystrons to 30±0.05°C. The fluctuation of the temperatures in both systems was reduced by one order of magnitude, which greatly contributed to improvement in the stability of FEL and PXR.

LEBRA 125MEV ELECTRON LINAC

The LEBRA 125MeV electron linac consists of a DC electron gun, a pre-buncher, a buncher, and three 4m regular accelerator tubes. The RF power is supplied using two S-band klystrons. The layout of the LEBRA linac is shown in Fig. 1. The specifications of the linac are listed in table 1.

The FEL lasing was achieved in the wavelength region from 0.855 to 6 μm with the maximum output energy of about 60mJ/macropulse at a wavelength of 1725nm. The 2nd ~ 4th harmonics of the FEL wavelength have been generated by means of non-liner BBO crystals. The maximum conversion efficiency of the 4th harmonics has been approximately 10% of the fundamental FEL power.

The coherent monochromatic PXR beam is currently available in the energy range from 5 to 34 keV with a large beam aperture diameter of 100mm. The PXR generator consists of a couple of Si (111) or Si(220) crystals, depending on the required X-ray energy, located in (+,-) configuration so that the X-rays emitted from the first electron target crystal are reflected by the second crystal to the direction of the fixed output port.

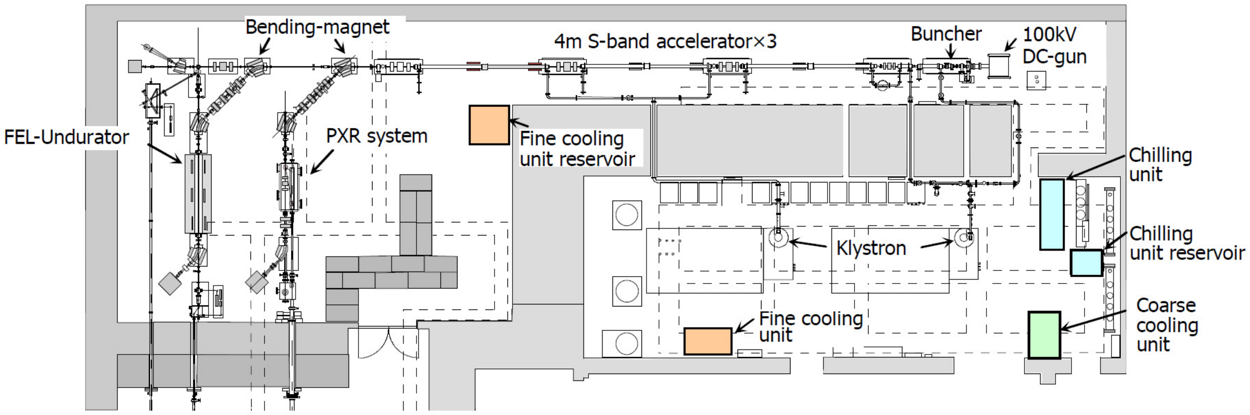

Figure 1: Layout of the LEBRA 125MeV linac and the cooling water system.

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These FEL and PXR light sources have been used for a variety of users' experiments.

Table 1: Specifications of the LEBRA electron linac.

Maximum Electron Energy	125	MeV
DC gun voltage	-100	kV
Accelerating RF frequency	2856	MHz
Klystron peak RF power	30	MW
Number of klystrons	2	
Macropulse duration	5~20	µs
Repetition rate	2~12.5	Hz
Macropulse beam current	200	mA
Energy spread (FWHM)	0.5~1	%

THE COOLING WATER SYSTEM

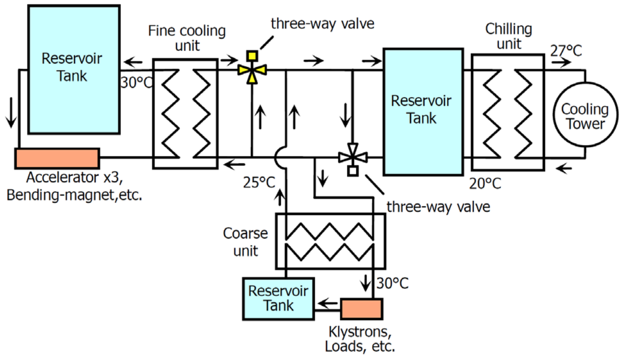

Figure 2: Block diagram of the cooling water system.

The cooling water system consists of the cooling tower, the chilling unit, the coarse cooling unit and the fine cooling unit. The layout of the cooling water system is illustrated in Fig. 1, and the system diagram is shown in Fig. 2. The klystrons and the klystron focus magnets are cooled by the course cooling water system. The RF waveguides, the accelerating tubes, the bending magnets, Si crystals for the PXR generator are cooled by the fine cooling water system.

The heat generated in each accelerator element is removed with the cooling water and transferred through the heat exchanger to the chilled water. The cooling water temperature is stabilized with the three-way valve located near the cooling unit in the chilled water line. Also the chilled water temperature is stabilized by mixing the returned and the reserved waters with the three-way valve located near the reservoir tank. With this system the temperature stability of 30±0.01°C was achieved for the fine cooling water, and 30±0.05°C for the coarse cooling water. The difference in the stability between the two lines is mainly due to the difference of the water flow paths as illustrated in Fig. 2.

DEPENDENCE OF THE BEAM ENERGY ON THE FINE COOLING WATER TEMPERATURE

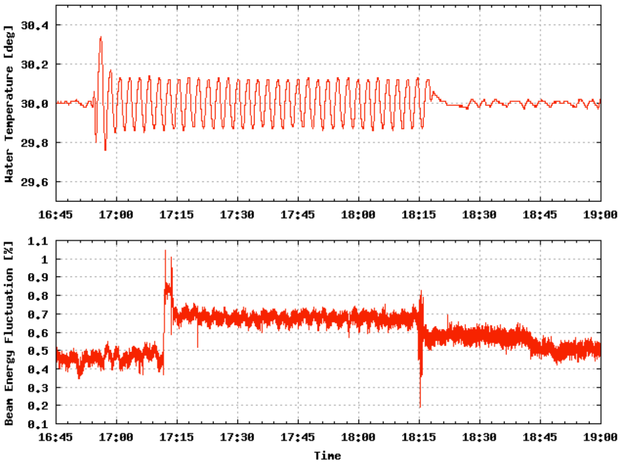

Figure 3: Time variation of the temperature of the cooling water (upper) and the beam energy (lower).

The three-way valve for the fine cooling unit has been operated by using the PID controller SDC36 made by YAMATAKE Corporation. The PID parameters for the controller have been adjusted to obtain the best temperature stability.

In order to investigate the dependence of the electron beam energy and the FEL power on the fine cooling water temperature, the PID parameters were intentionally mismatched so that the temperature of the cooling water showed a periodical change approximately with the amplitude of 0.1°C and the period of 150 s. The behaviour of the electron beam energy was deduced from the displacement of the beam orbit which was detected by using the non-destructive beam position monitor located in the dispersive section of the 90 degree achromatic bending system..

The experiment was carried out at the electron beam energy of 100 MeV and the FEL wavelength of 1.8 µm. Figure 3 shows the variation with time of the fine cooling water temperature and the electron beam energy. During this experiment no adjustment was made for the linac except for the excitation current of the quadrupole magnets in the achromatic bending system at 17:12 and the beam energy at 18:15. It is clear that the electron beam energy has changed in accordance with the periodical change in the fine cooling water temperature. The result showed that the rate of the beam energy change is approximately 0.3 %/ °C.

DEPENDENCE OF THE FEL POWER ON THE FINE COOLING WATER TEMPERATURE

Fig. 4 shows the variation with time of the FEL power and the fine cooling water temperature which is identical to the one in Fig. 3. The FEL power was measured by means of an infrared power meter at the monitoring port in the optical transport line. The higher harmonics of FEL were reflected before the power meter with a cold mirror in the direction of the monochromator for the wavelength measurement.

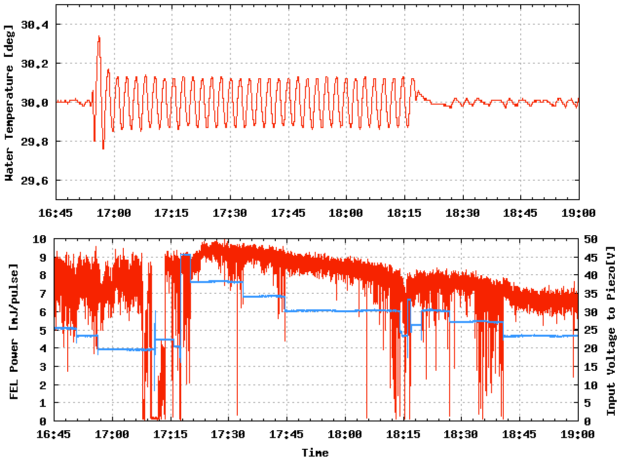

Figure 4: Time variation of the temperature of the fine cooling water (upper), the optical power of FEL (lower, red) and the adjusted input voltage to the piezo actuator (lower, blue).

Investigation over years at LEBRA resulted in approximate rate of 0.1mm/°C as the dependence of the FEL resonator length on the temperature of the floor concrete under the undulator. In daily operation of the FEL system, the resonator length has been tuned to the FEL power as high as possible by means of the piezo actuator that makes shift of the mirror position along the beam axis. Therefore, the input voltage to the actuator was changed during the experiment as shown by the blue line in Fig. 4. In the time from 17:06 to 17:25, also adjusted were the beam orbit in the FEL line and the orientation of the FEL mirrors.

From the experimental result the periodical change of ±0.1°C in the fine cooling water temperature does not seem to make significant effect on the FEL power, though the power drifted slowly with time.

After 17:25 in Fig. 4, the FEL power shows significant loss of stability at around 17:33, 17:45, 18:15, 18:27 and 18:42, respectively. However, as seen from the change in the piezo actuator input voltage, the stability was easily recovered by the adjustment of the optical resonator length at each time except for at around 18:15.

The large loss of stability at around 18:15 was once recovered by the adjustment of the piezo actuator. However, the successive instability was not recovered only by the piezo actuator. Then the operator had to try and adjust the energy and the orbit of the electron beam, though there seems to be no conspicuous change prior to the occasion as seen in Fig. 3.

CONCLUSION

Periodical change in the linac fine cooling water temperature, introduced with 0.2°C peak-to-peak, has resulted in negligibly small fluctuation of the FEL output power. This suggests that the LEBRA linac cooling water system offering the temperature regulation within 0.02°C has sufficient performance for stable FEL lasing. The piezo actuator has been quite efficient for recovering the FEL power stability that can be lost by the change in the resonator length.

The FEL power has been confirmed to drift slowly with time by some reasons other than the fine cooling water system. Also there seems to be some reasons caused a drastic loss of the FEL power stability.

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