STUDY ON ELECTRON BEAM STABILIZATION IN KU-FEL

Kensuke Okumura#, Heishun Zen, Motoharu Inukai, Yusuke Tsugamura, Kenta Mishima, Torgasin Konstantin, Hani Negm, Omer Mohamed, Kyohei Yoshida,, Toshiteru Kii, Kai Masuda, Hideaki Ohgaki
Institute of Advanced Energy, Kyoto University
Gokasho, Uji, Kyoto, Japan, 611-0011

Abstract

A stable electron beam is essential for a stable FEL operation. In Kyoto University MIR-FEL facility (KU-FEL), a Beam Position Monitor (BPM) system consisting of six 4-button electrode type BPMs and signal processing unit was installed for monitoring of the electron beam position. Fluctuations of the electron beam position have been observed both in horizontal and vertical directions. In horizontal direction, the main fluctuation source could be the energy fluctuation of the electron beam generated by the thermionic RF gun. One of candidate of the energy fluctuation, the cavity temperature of the RF gun has been suspected, because the gun is operated in detuned condition which enhances beam energy dependence on the cavity temperature. Another candidate is the fluctuation of the RF power fed to the RF gun. The both effects were experimentally investigated. We observed a small fluctuation of the beam energy corresponding to the cavity temperature fluctuation. But the large fluctuation of the RF power which was induced by change of temperature of ferrite slabs in the 4-port circulator was clearly observed. A temperature-stabilized water circulation system will be prepared for the ferrite slabs to stabilize the RF power fed to the RF gun.

INTRODUCTION

Stabilization of an electron beam is crucial to stabilize the FEL power fluctuation. We have been working on our resonator type MIR-FEL to supply stable FEL beams to users in Kyoto University FEL facility, KU-FEL. We have introduced 4-button type Beam Position Monitor (BPM) to construct a beam position feedback system. As the result, the beam position displacement in horizontal and in vertical were reduced down to a few tens μm. The FEL power fluctuation was largely reduced from its' original value of 40% to 20% [1]. However, further studies are required to find the source of the fluctuation of electron beam position. In horizontal direction whose position fluctuation is 2-3 times larger than that in the vertical direction, the energy fluctuation of the electron beam should be dominant. Therefore we investigate the energy fluctuation in the electron beam, especially in the RF gun. In this paper we will briefly describe the result of examination, proposed measures, and future plan.

REDUCTION OF FLUCTUATION OF BEAM POSITION BY BPM SYSTEM

The KU-FEL consists of 4.5-cell S-band thermionic RF gun, a 3-m accelerator tube, a 1.8-m Hybrid undulator, and an optical resonator [2]. Figure 1 shows the structure of KU-FEL.

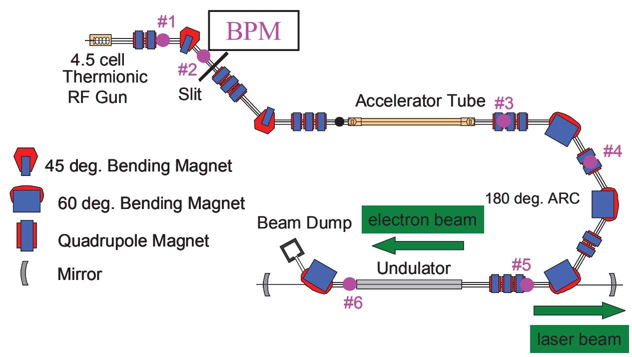

Figure 1: Layout of KU-FEL

In Figure 1, #1-#6 indicate the position of each BPM. We focus on the feedback system in the low-energy part (from RF gun to the entrance of accelerator tube). At first, the set value of Klystron high-voltage power supply (Klystron voltage) was adjusted by using the information of the horizontal movement obtained from BPM #2 to keep the energy of the electron beam constant. The fluctuation of electron beam position was substantially reduced because of this feedback control system. Moreover, the fluctuation of electron beam position which was not able to be compensated by above feedback control system was compensated by the other feedback system which uses the horizontal steering magnet. As the result, it became possible by combining these two feedback systems to reduce the fluctuation of electron beam position in the low energy part. We succeeded to stabilize the FEL power fluctuation [1].

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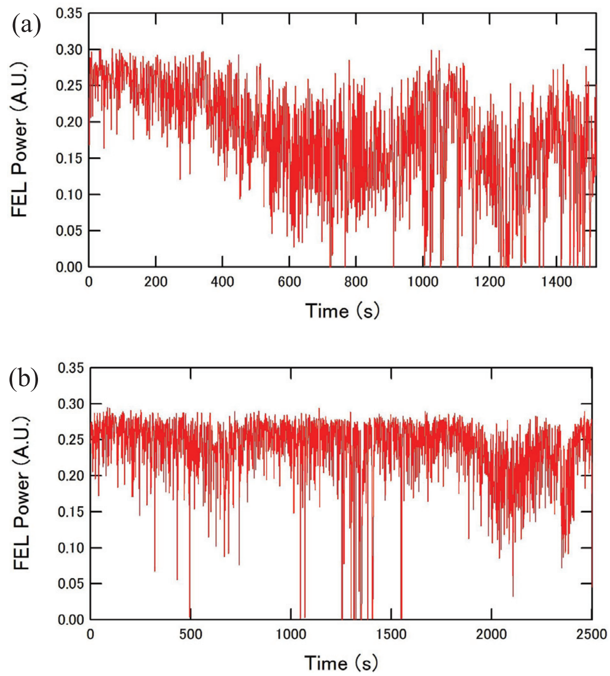

Figure 2: The fluctuation of FEL Power (a)without feedback control (b)with feedback control[1].

A SOURCE OF ENERGY FLUCTUATION AT THERMIONIC RF GUN

The source of the energy fluctuation in the electron beam from the RF gun is the fluctuation of the electric field at the resonant cavity. The fluctuation of the electric field could be caused by following three elements; the beam loading, the cavity temperature, and the microwave power fed into the RF gun. Among these three contributions, the change of the beam loading should be small in KU-FEL, because the feedback control in the cathode power has been installed [1]. Moreover we are operating the RF gun in detuning mode to reduce the back-bombardment effect [3]. Therefore, the stability of the cavity temperature is more critical than usual RF guns under the resonant condition. If a 1°C temperature change arises, 45 kHz of resonance frequency will change and this will accompany the energy fluctuation of 772 keV in our case. Therefore, the effect of energy fluctuation caused by the change of the temperature of the resonant cavity seems to be large, and we investigated the effect at the beginning.

CAVITY TEMPERATURE DEPENDENCE ON ENERGY FLUCTUATION

The platinum resistance temperature detector with a temperature coefficient of 1.3851 ppm/°C was attached to the outside wall of the resonant cavity to measure the temperature of the RF gun. We measured the cavity temperature by measuring the resistance value of a resistance temperature sensor with four-terminal method using 2400 type Source Meter made by KEITHLEY. We can observe the change of the klystron voltage as the change of the cavity voltage because of aforementioned beam energy feedback. Figure 3 expresses the relation between the cavity temperature and klystron voltage when air temperature was 17.7-21.1 deg. C. As seen in Fig.3, the relation between the cavity temperature and the klystron voltage could not be confirmed, but a saw tooth wave-like pattern was observed in the klystron voltage. We suspected that the origin of the saw tooth pattern was the temperature change of the cooling water which has cooled the collector of a klystron, the solenoid coil, RF circulator, the beam slit, etc. Therefore we measured the cooling water temperature precisely. The result is illustrated in Fig.4 and the relation between the cooling water temperature and the klystron voltage was clearly confirmed.

From these results, the beam energy fluctuation could be originated by the fluctuation in the cooling water temperature, but not in the cavity temperature. In order to figure out the source of this relation, we surveyed on the RF components which cooled by the cooling water system in KU-FEL.

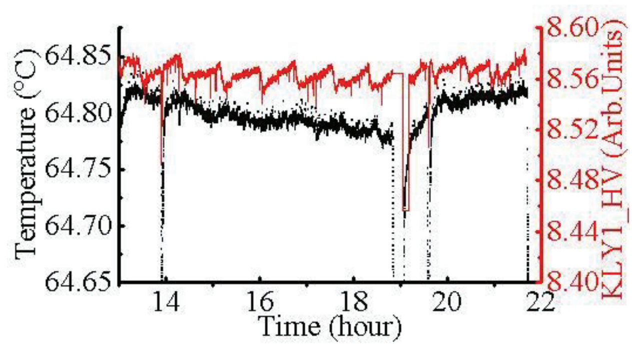

Figure 3: Effect of Cavity temperature on beam energy.

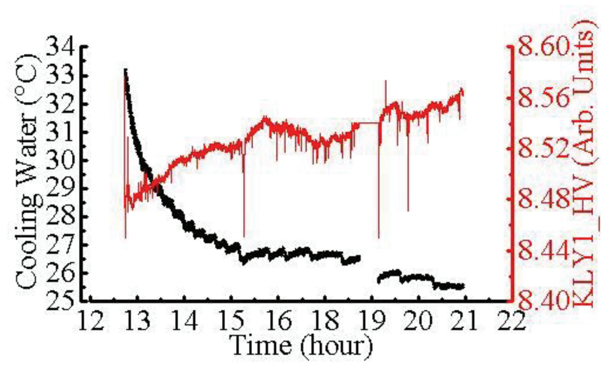

Figure 4: Relation between Cooling Water and Klystron High voltage.

CLARIFICATION OF THE FACTOR OF ENERGY FLUCTUATION

Change of Microwave Power by Cooling Water

The diagram of the cooling water related to the RF gun is shown in Figure 5.

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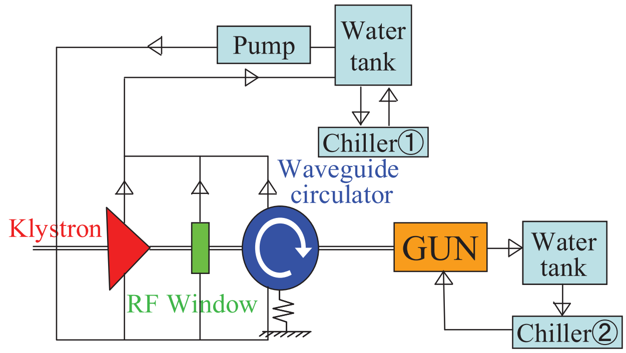

Figure 5: Circulation route of cooling water.

Then we checked each component. We measured the microwave power before and after circulator with turning off the beam energy feedback control. At the same time, we changed the temperature of cooling water by turning off and on the chiller. The result is shown in Figure 6.

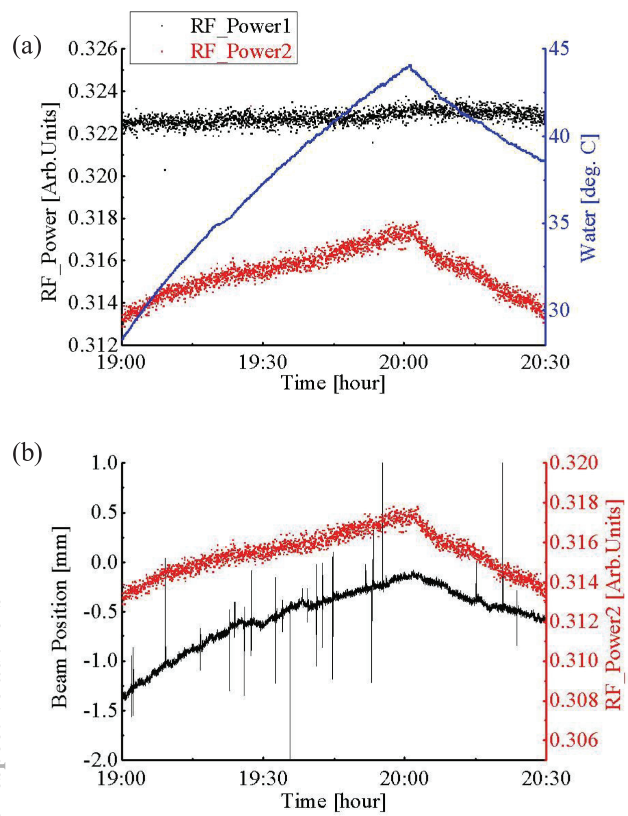

Figure 6: RF input power relative to (a) cooling water or (b) beam position at BPM#2.

From the result of Figure 6(a), the large fluctuation in the microwave power caused by the temperature change of the cooling water was confirmed at the output side of the circulator. Moreover, the microwave power fed into the RF gun was still increasing with the rise of the temperature of the cooling water. The optimum temperature of cooling water at which the RF loss in the circulator shows a minimum could exist more than 35°C. We measured the relation between the temperature of cooling water and the RF transmission of the circulator. The result is shown in Figure 7 and we found that the optimum temperature of water for cooling circulator was around 40 to 50 degree C.

From the result of Figure 6(b), a relation between the fluctuation of the microwave power fed into the RF gun and the fluctuation of the electron beam position at BPM #2 was observed. As a consequence, it is possible to suppress the fluctuation of electron beam position by reducing the temperature change of cooling water flowing through the circulator.

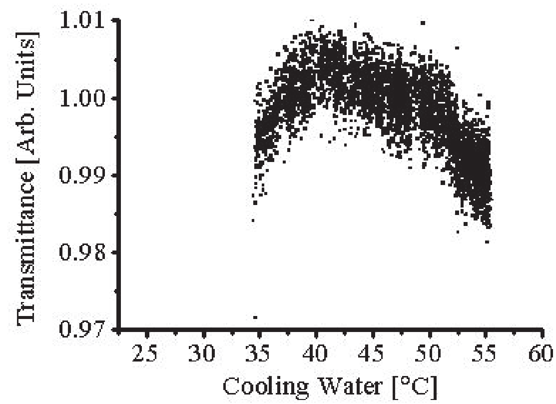

Figure 7: Optimum temperature of water for cooling circulator.

The temperature dependence of the RF transmission rate in the circulator should be originated from the change of the characteristic of the ferrite slab cooled by the cooling water (Fig.8).

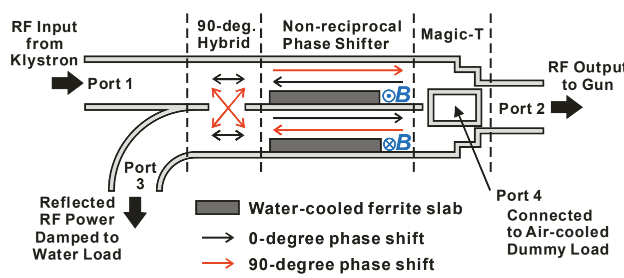

Figure 8: Structure of 4-port waveguide circulator.

CONCLUSION

Studies on the source of the fluctuation of the electron beam to improve the stabilization of the KU-FEL have been conducted. We found that the fluctuation of the electron beam energy was induced by the temperature fluctuation of the RF circulator. Moreover, the optimum temperature of the cooling water to minimize the RF loss in the circulator was found.

We plan to revise the cooling water system to suppress the temperature fluctuation of the circulator.

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REFERENCES

[1] H. Ohgaki, H. Zen, Y. W. Choi, H. Imon, T. Kii, R. Kinjo, T. Konstantin, K. Masuda, H. Negm, K. Okumura, M. Omer, M. Shibata, K. Shimahashi, K. Yoshida, "DEVELOPMENT OF BEAM POSITION FEEDBACK CONTROL SYSTEM IN KU-FEL", Proceedings of IPAC2013, pp.2968-2970 (2013).

[2] H. Zen, K. Okumura, K. Shimahashi, M. Shibata, H. Imon, T. Konstantin, H. Negm, M. Omer, K. Yoshida, Y.W. Choi, R. Kinjo, M. A. Bakr, T. Kii, K. Masuda, H. Ohgaki, "IMPROVEMENT OF KU-FEL PERFORMANCE BY REPLACING UNDULATOR AND OPTICAL CAVITY", Proceedings of FEL2012, Nara, Japan, pp. 449-452 (2013).

[3] H. Zen, T. Kii, K. Masuda, R. Kinjo, K. Higashimura, K. Nagasaki, H. Ohgaki, "Beam Energy Compensation in a Thermionic RF Gun by Cavity Detuning", Nuclear Science, Vol. 56, Issue 3, pp.1487-1491, (2009).

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