Study to Improve Longitudinal Lasing Stability of the UVSOR-FEL Deteriorated by Unstable Optical Cavity

Shigeru KODA, Masahito HOSAKA, Jun-ichiro YAMAZAKI, and Hiroyuki HAMA
Institute for Molecular Science
38, Nishigonaka, Myodaiji, Okazaki, 444-8585, Japan

Abstract

A newly developed optical cavity for free electron laser (FEL) experiment was recently installed on the UVSOR storage ring. Although lasing stability was much more improved than the former UVSOR-FEL, a sinusoidal time jitter of FEL micropulse with a frequency of ~ 60 Hz arose, which was found to be due to mechanical vibration of a cavity mirror. In addition, slow drift of synchronism between the electron bunch and the FEL micropulse was continuously observed. In order to keep the synchronization for a stable FEL operation, we have been developing a feedback system that may control the revolution time of the electron bunch by regulating an RF frequency. To detect time deviation of the optical bunch from the synchronous phase of the electrons, we have tried to observe phase angle of a higher harmonic of the FEL round-trip frequency relative to the accelerating RF signal.

1 Introduction

After an achievement of lasing at the shortest wavelength of 239 nm at that time [1], the UVSOR-FEL had been shutdown because of a conflict between the FEL optical cavity and a new beam line for synchrotron radiation (SR). The new FEL system was designed to have sufficient stability for user applications such as two-color experiments with SR and high energy gamma ray production for nuclear science [2].

Since unstable optical cavity would spoil the quality of the FEL as a light source, design of the system was concentrated to reduce mechanical vibrations propagated from the floor of the experimental hall, which annoyed us in the former FEL experiment. However improvement of the optical cavity seemed to be insufficient because unexpected time jitter of the FEL micropulse arose. The temporal jitter of the micropulse was modulated with a standard electricity frequency of 60 Hz, and considered to originate from sound noise in the hall. It is obviously important to maintain synchronization between the electron bunch and the FEL micropulse. In other storage ring FEL (SRFEL) facilities, feedback systems have been developed to keep stability of optical cavities [3,4].

Since longitudinal instability seemed to be crucial for the UVSOR-FEL, we are going to apply a fast feedback to the RF frequency to keep the best synchronism and then stable FEL oscillation. As a first step to develop the feedback system, we have tried to detect the temporal deviation of the FEL micropulse from the electron bunch center.

In this article, we introduce the newly installed FEL optical cavity and its fundamental performance. Preliminary result of the phase detection between the FEL pulse and the synchronous phase of the electron bunch is also presented.

2 New Optical Cavity of the UVSOR-FEL

Detail of the optical cavity is shown in Fig. 1. To escape from complicated mechanical resonances and to decrease amplitude of mechanical vibration, the structure of the mirror chamber was simplified. Number of control

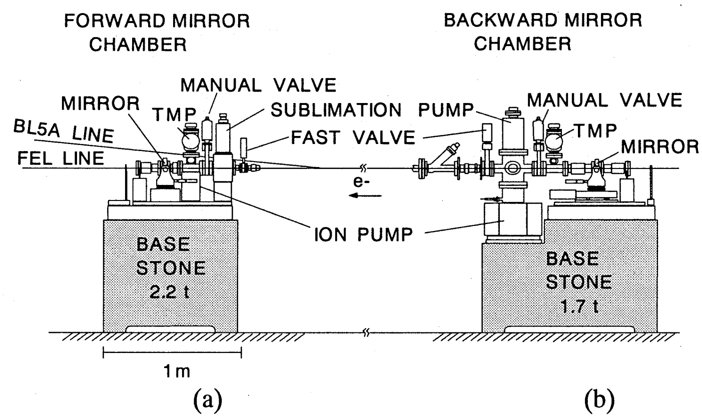

Fig. 1 The mirror chambers of (a) forward and (b) backward sites for the electron beam.

axes for cavity mirrors were reduced from ten axes of the former UVSOR-FEL[3] to five axes. Heavy stones were employed for the bases of the mirror chambers, because the stone is able to be shaped with high precision and is relatively heavy, which is effective to dump the vibration.

3 Detuning Response of the FEL Macrotemporal Structure

Detuning dependence for the RF frequency was measured as two-dimensional time spectra by a dual-sweep streak camera. Typical cases of lasings at a wavelength of 520 nm are shown in Fig. 2. In a region of the small detuning around the best synchronism, a stable CW lasing was observed, which is shown as a case of $\Delta f_{RF} = 0$. In the region of the large detuning of Δf_{RF}=10 Hz, a macropulse structure arose. In the former UVSOR-FEL experiment, the lasing around the best synchronism was unstable and it was difficult to maintain the CW lasing [1].

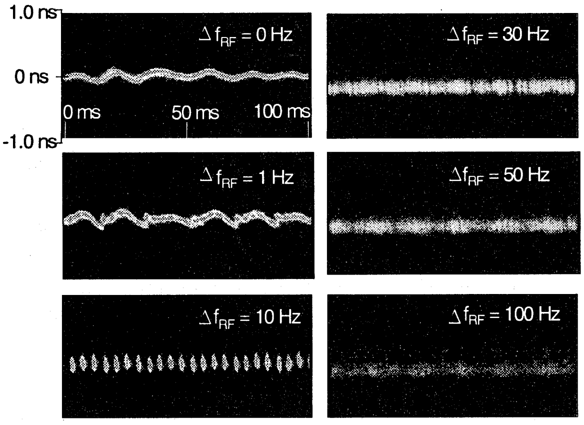

Fig. 2 Typical detuning dependence in the FEL lasing at the wavelength of 520 nm. Time structures of the CW, the macropulse and the quasi CW lasings were observed in order of detuning of the RF frequency. The value of Δf_{RF} means detuning frequency.

In the new system, the CW region was clearly observed and stable in both points of the micropulse time jitter and the FEL intensity. However the reduction of the mechanical oscillation seemed to be insufficient. A time-jitter oscillation, which did not destroy the CW lasing, was also observed throughout the lasing experiment. There may be a motion of the bellows of the mirror chamber owing to large sound noises of 80 phone and floor vibration in the experimental room.

4 Correlation of Mechanical Oscillation and the FEL Instability

It was found that the micropulse time jitter in the CW lasing correlated strongly with the mechanical oscillation of the cavity mirror. Putting a vibration sensor on the top of the mirror mounts, it was observed that the backward mirror had a large amplitude of a 60 Hz oscillation in a direction of the longitudinal axes of the optical cavity. In

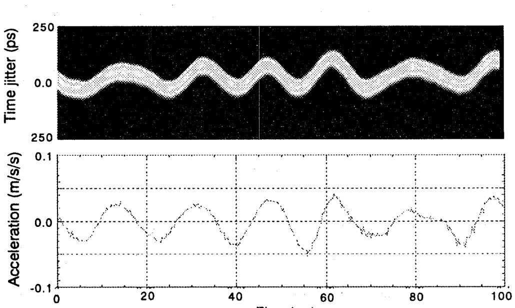

Fig.3 Clear correlation between mechanical oscillation of the backward cavity mirror (lower figure) and the micropulse time jitter (upper figure).

addition, it was clearly observed that the phase of the time jitter of the FEL micropulse correlated to the phase of the sensor signal as shown in Fig. 3. The correlation of the mechanical oscillation and the time jitter of the micropulse was also investigated by a computer simulation, which involved the effect of the periodic movement of the backward mirror in the longitudinal axes with the frequency of 60 Hz. In the simulation, increase of the beam energy spread was assumed to be proportional to the produced photon energy and a Gaussian bunch shape was used as a profile of the FEL gain[5]. The result is shown in Fig. 4. It was found that the oscillation amplitude was about 0.4 μm in the actual experiment, and then the time jitter amplitude reached 70 ps. There was a good agreement between the simulation and the measurement. This means that the mechanical oscillation must be reduced to less than 0.1 μm for decreasing the time jitter in order of 10 ps, which is roughly temporal width of the micropulse.

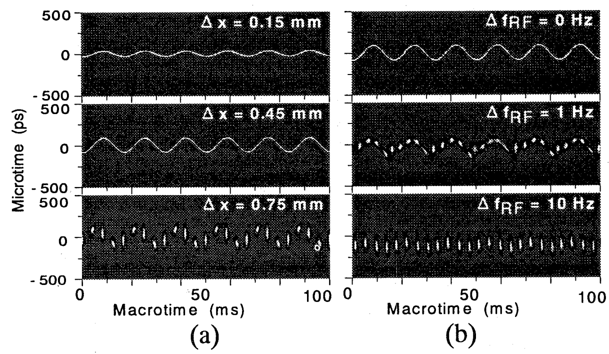

Fig. 4 (a) The simulation result of the correlation with the mirror oscillation of 60 Hz and the laser power of the intracavity. The amplitude of the mechanical oscillation is shown as Δx. (b) The simulation result with the mirror oscillation of 60 Hz and small RF detuning in case of the oscillation amplitude of 0.45 μm.

In a simulation of which involves both the mechanical oscillation and small and constant RF detuning about 1 Hz for the RF frequency of 90 MHz, complicated fluctuation in both the time jitter and the FEL intensity is appeared, which agrees well with the experimental data shown in case of Δf_{RF}=1 Hz of Fig. 2. It was supposed that a mechanical displacement of the cavity mirrors induced by thermal deformation might cause additional detunings in the actual experiment, because the RF frequency had to be frequently tuned to obtain the best synchronism.

5 Elemental Study for the FEL Stabilization

To reduce the FEL instability and maintain the best synchronism, we consider to develop a feedback system, which regulates the RF frequency to synchronize the revolution frequency of the electron bunch with the FEL round-trip frequency by detecting a time deviation of the FEL micropulse from the electron bunch center. As a first step, the time deviation was measured as a function of the RF detuning frequency by the streak camera. A result is shown in Fig. 5. Around the CW lasing region, the time deviation seems to be most sensitive to change of the RF frequency and saturates in large detuning regions.

Taking the time jitter oscillation of 60 Hz into account for the development of the feedback system, the time deviation has to be measured continuously with relatively fast response. We developed a test system to detect the time deviation as a phase angle of the FEL micropulse relative to the accelerating RF. The schematic diagram is

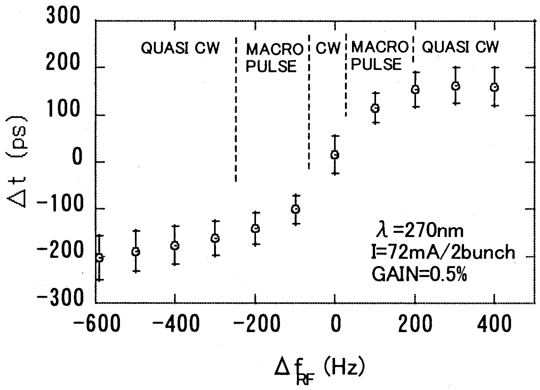

Fig. 5. The time deviation Δt of the FEL for the electron bunch plotted as a function of the RF detuning frequency Δf_{RF}. Error bar means 1 σ of the FEL intensity distribution for time.

shown in Fig. 6. A biplanar photo-tube HAMAMATU R1328U-02 with a fast raise time of 60 ps was employed to detect the FEL light. The photo-tube signal is filtered and an extracted harmonic component is compared with the accelerating RF signal. To obtain a better resolution of the phase angle, we have chosen 270 MHz, the 24th harmonic of the FEL round–trip frequency, which corresponds to the 3rd harmonic of the RF frequency. Phase angle of one degree in 270 MHz equivalents to a time deviation of 10 ps.

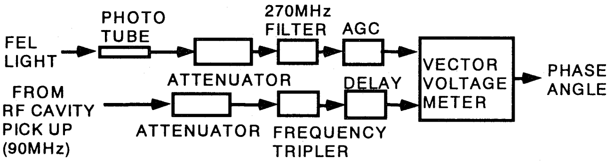

Fig. 6 Test system for detection of the phase angle.

The preliminary result is shown in Fig. 7. In the CW lasing region, the response curve of the phase deviation has roughly a constant gradient with about 2 deg/Hz in the CW region. Since the frequency resolution is 0.1 Hz in actual control of the RF frequency, the resolution to detect the phase angle in the CW region is required to be smaller than 0.2 deg.

There are a bump and a dip of the phase angle curve in the macropulse lasing region. The phase detection circuit seemed to have an intermediate response because continuos and no lasings occurred alternately in the macropulse mode. In the quasi CW regions, we observed that the phase angle went back to the value at the best synchronism as the detuning increased. We thought that the intensity of the spontaneous emission is not negligible in the large detuning regions.

As one can see in Fig. 7, the sign of the phase angle changes only at a frequency of the best synchronism (except for very large detuing regions), so that we can find out the change direction of the RF frequency to decrease the time deviation of the FEL micropulse in almost all lasing regions.

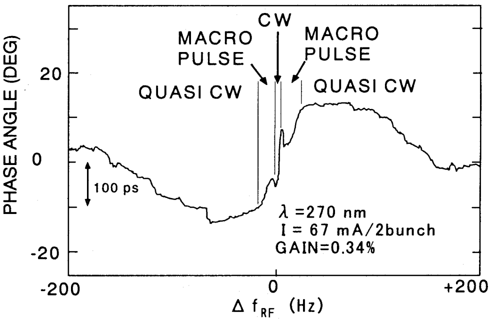

Fig. 7 Measured phase angle for the RF detuning frequency. In the vertical axis, the angle of 10 degree corresponds to 100 ps in the time deviation and the origin is based on the phase at the best synchronism.

6 Summary

The FEL instabilities due to the mirror vibration and the slow drift of the synchronism were observed. A coupling of both instabilities introduces another complicated lasing instability.

We consider to develop the feedback system, which vary the RF frequency to stabilize the FEL. As a first step, we carried out two studies of (1) the correlation of the time deviation and the RF frequency and of (2) the detection of the phase angle between signals of the FEL light and the RF.

The change direction of the RF frequency to stabilize the FEL can be decided by the sign of the phase angle. As the present phase detection system can respond to slow change of the time deviation, the system may be applied to the feedback system for the slow drift of the synchronism. In an application for the fast instability of the FEL such as the time jitter oscillation of 60 Hz, we have to consider further about the response time of the phase detection.

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