PRESENT STATUS AND FUTURE PROSPECTS OF THE UVSOR STORAGE RING FEL

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Abstract

At the UVSOR facility, experiments on a storage ring free electron laser (FEL) have been performed using a helical optical klystron. Recently an upgrade of the storage ring has been made and the performance of the electron beam has been much improved. The improved quality of the electron beam is of great advantage to the storage ring FEL. We recently began an FEL experiment with the upgraded storage ring. Although detailed study is in progress, FEL lasing around 420 nm has been obtained. We are also considering a project to upgrade the FEL system.

INTRODUCTION

The UVSOR is the 2nd generation synchrotron light sources in VUV region. Experiments on SRFEL have been performed since early 1990's. In 1995, a helical optical klystron was installed and the performance of the FEL improved remarkably because the degradation of the cavity mirror is much reduced [1]. Shortly after the installation, lasing in the UV (240 nm) region has been achieved.

From April to August, 2003, the UVSOR storage ring was shutdown for an upgrade; most of the elements were replaced with new ones and it was successful commissioned in July [2]. The chief aim of this upgrade is to provide users with brighter SR from undulator; modify the magnetic lattice configuration in order to reduce the beam emittance, and to extend the straight sections for undulators. The transverse emittance is reduced to 1/6 of the previous value and is close to that of third generation light sources. As these changes are very favourable to the SRFEL, we expect successful lasing in shorter wavelength.

In October 2003, we started experiment with the upgraded storage ring (UVSOR-II) and the first lasing was achieved on December 1st. In this paper, we describe preliminary results of an FEL experiment with the UVSOR-II and future plan of the UVSOR-FEL.

ARRANGEMENT OF BEAM TRAJECTORY FOR FEL EXPERIMENT

Before an FEL lasing experiment with the UVSOR-II, we arranged a beam trajectory by measuring spontaneous radiation spectra from the helical optical klystron (HOK). At first, we aligned the electron beam with the magnetic center of HOK. In this arrangement, the deduced modulation factor [3] from the spontaneous spectrum was

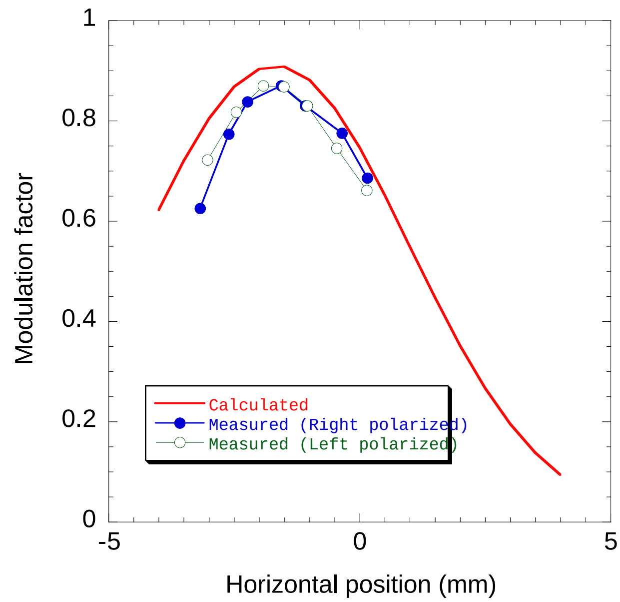

Figure 1: Measured modulation factor as a function of the horizontal beam position for both right/left polarized condition of HOK. The solid line is a calculation using Equation 1.

small as compared with calculated one. Since an FEL gain is proportional to a modulation factor, the small value is disadvantageous to FEL lasing. Accordingly we shifted the beam trajectory in HOK and measured the spectra. Figure 1 shows dependency of the modulation factor on the horizontal electron beam position from the magnetic center of HOK. As seen in the figure, the highest value is obtained when the electron beam is displaced by -1.5 mm from the magnetic center. We also shifted the horizontal angle, the vertical position and angle of the electron beam and found that the dependency of the modulation factor is very small.

In order to evaluate the experimental result, we performed numerical calculation and deduced a parameter N_d ; number of the waves passing over the electron beam in the dispersive section of HOK. The code Radia [4] was employed to evaluate magnetic field of HOK. It was found that N_d depends on the trajectory in the dispersive section due to an inhomogeneous distribution of the horizontal magnetic field in the horizontal direction. If the is expanded as:

$$N_d = N_{d0} + N_{d1}x\,, \tag{1}$$

where x is the horizontal beam postion. Then a degradation of the modulation factor is given as:

$$f_{\text{mod}} = \exp\left[-\left(2\pi N_{d1}\sigma_x\right)^2\right], \qquad (2)$$

where σ_x is the horizontal beam size in the dispersive section. The calculated modulation factor is compared with the experimental one in Fig.1. In the calculation, the effect from the energy spread of the electron beam is also taken into account. As seen in the figure, the experimental result is well reproduced by the calculation. As a result, we have determined the trajectory of the electron beam to be displaced by -1.5 mm from the magnetic center of HOK.

LASING EXPERIMENT WITH UVSOR-II

The FEL lasing experiment on the UVSOR-II storage ring was made with the wavelength in the visible region around 420 nm. The first lasing was obtained on December 1st shortly after an adjustment of the optical cavity. Looking at an extracted FEL power, we made more accurate adjustment of the cavity mirror. The round-trip reflectivity of the cavity mirror was evaluated by a ring-down method and the deduced value was 99.25 %.

Reducing an electron beam current, a threshold beam current was measured and the obtained value was 16 mA/2-bunch. Thus the FEL gain is estimated to be 0.75 % at the electron beam current of 16 mA/2-bunch. This value is compared with calculated FEL gain in Fig. 2. As seen in the figure, although the measured gain was higher than previous value of the UVSOR-I, it is smaller than the calculated one of the UVSOR-II. This indicates that the optimization of the FEL system has not been done satisfactory. We suppose that the adjustment of the overlap between the laser and the electron beam whose size is reduced in the upgraduation of the storage ring is not sufficient. We are going to employ correction magnets equipped inside HOK to maximize the overlap.

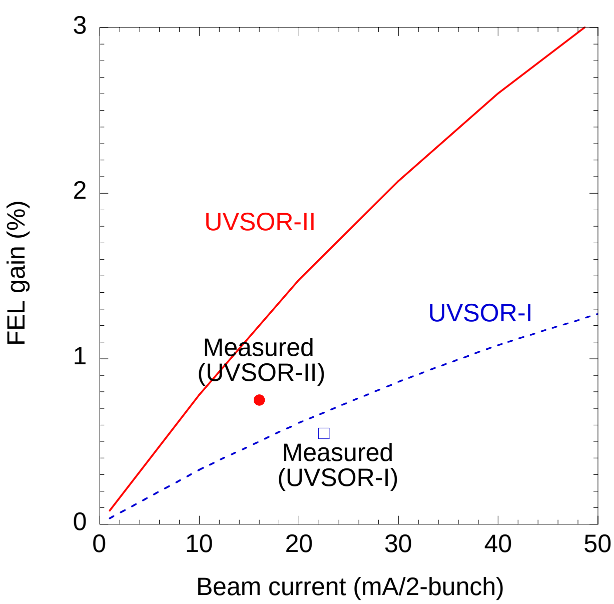

Figure 2: FEL gain as a function of the beam current. Measured gains for the UVSOR-I and UVSOR-II are compared with calculated ones.

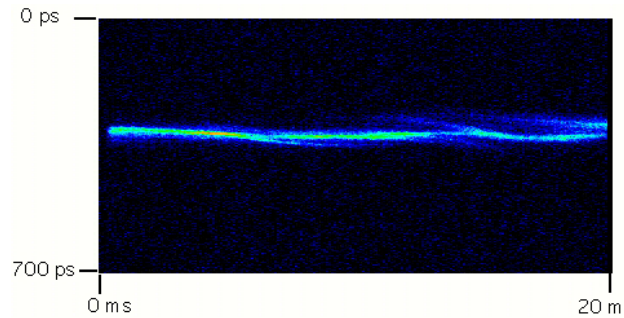

Figure 3: Temporal profile of the FEL at the beam current of 68 mA measured using a dual sweep streak camera.

In order to investigate characteristics of the lasing, we measured a temporal profile the FEL using a dual-sweep streak camera. Figure 3 shows one of obtained profiles. The measured shortest temporal width was 5 ps, but the stable lasing did not last more than 10 msec. This is because the electron beam was always suffered by the transverse/longitudinal instability during the measurement. The source of the instability is supposed to the interaction with the RF cavity system (main cavity and 3rd harmonic cavity). We are going to optimize the operating point of the storage ring to suppress the instability.

FUTURE IMPROVEMENT OF THE STORAGE RING AND THE FEL

At the UVSOR-II, where the emittance is reduced to 1/6 of its previous value, the lifetime will be shorter and disadvantageous for SR uses. The most efficient way to improve the lifetime is to increase the voltage of acceleration of rf cavity. In the present system the voltage is only 46 kV, and it is apparently too low. It is already known that the performance of the presently employed rf cavity is not good enough to be used with high voltage. Hence we are planning upgrading the rf cavity. In our estimate, cavity voltage of 200 kV can be obtained with the present power supply system if the old cavity is replaced by a new one. The high voltage of the rf cavity has a five times longer Touscheck lifetime. This high cavity voltage is also advantageous to the SRFEL. Since the FEL gain is proportional to its electron density in a bunch, the reduced bunch length due to the high cavity voltage will enhance the FEL gain by a factor of 2.

We are considering constructing a new optical klystron for FEL lasing in the VUV region in our future projects for UVSOR-FEL. Since the FEL gain using an optical klystron is proportional to the square of the number of undulator periods, a long optical klystron is favourable for an SRFEL. As mentioned earlier, the straight section has been elongated from 3 m to 4 m in UVSOR-II, which allows the installation of a longer optical klystron. However, its length is much smaller than those of the third generation light sources such as Duke and Elletra. Therefore, the new optical klystron should have as many number of periods as possible within the limited length, and also the optical klystron should have sufficient K-value. In addition the polarity should be helical because of high gain and absence of higher harmonics on the axis. These requirements can be fulfilled if one uses an in-vacuum short period helical optical klystron. The narrow gap of the in-vacuum optical klystron allows a sufficiently high K-value. We have successfully installed two in-vacuum undulators at UVSOR; therefore, we have adequate experience in installation.

We began calculations using the code Radia. The calculation was based on the assumption that the helical undulator was of Apple-2 type. Although the calculation is in progress, the immediate solution is to employ a period of 65 mm to compensate the FEL gain and the longest wavelength at the minimum gap length (14 mm). In this case the expected FEL gain is about 5 times higher as compared to the case using helical optical klystron. With all these improvements, including high cavity voltage and in-vaccum helical optical klystron, the expected FEL gain at a beam current of 20 mA/bunch is 30% at a wavelength of around 200 nm.

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