Light Source Developments by Using Relativistic Electron Beams

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This project involves researches and developments on synchrotron light source, free electron laser, beam physics and their related technologies. Most of these works are performed at the UVSOR-II electron storage ring and its injector.

1. Developments on UVSOR Accelerators

In these years, we have been preparing for a new injection method called top-up injection at UVSOR-II, which would remove the serious short beam lifetime problem caused by the small emittance and the low electron energy.[1)] In this operation scheme, electron beam is re-filled with a short interval, typically one minute, to keep the beam current almost constant.

In 2008, we have started test operation with the top-up injection on every Thursday night. Although the users experiments are greatly improved by the high and constant beam intensity, it was also found that, in some beam-lines, the instantaneous electron orbit movement during the injection affected the experimental data. We prepared a system to deliver beam injection timing signals to the beam-lines that enables the users to stop the data acquisition during the injection. We have also prepared a feedback system to stabilize the injection efficiency. In July 2010, we have started operating the machine with the top-up injection fully in the users beam time. A typical beam current history in a week is shown in Figure 1.

In spring 2010, we have reconstructed a part of the storage ring and the beam transport line to create a new 4 m straight section to install a new undulator which would be dedicated for light source developments. As shown in Figure 2, the beam transport line was extended, the injection pulse magnets, the RF cavity and some instruments for beam diagnostics were also moved. After the three month reconstruction work, the accelerator was successfully re-commissioned on schedule. An undulator system is under construction, which will be installed in the straight section in spring, 2011.

We are investigating some possibility of further upgrade of UVSOR-II as a future plan in near term. It was found that, by

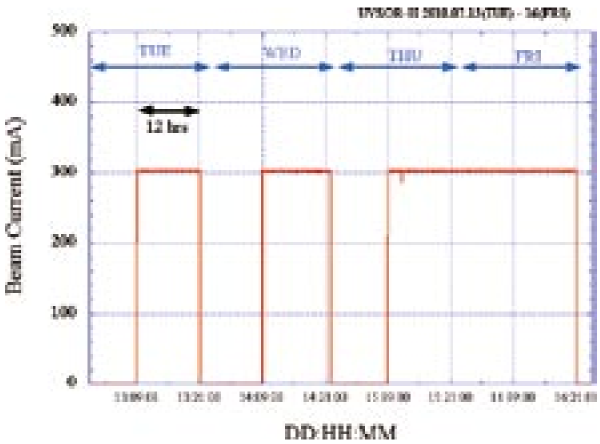

Figure 1. Beam current history in the top-up test operation in a week. The ring is operated for 12 hours on Tuesday and Wednesday, and 36 hours from Thursday to Friday in the top-up mode as keeping the beam current at 300mA.

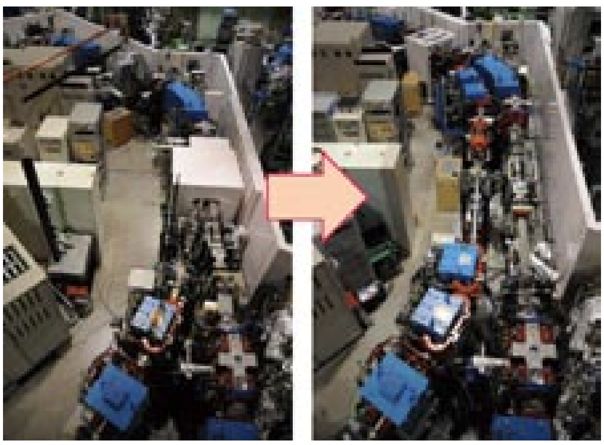

Figure 2. A part of he storage ring and the beam transport line in spring 2010, before the reconstruction (left) and after (right). The beam transport line was extended and a new 4m straight section was created in the ring. The devices colored in blue are bending magnets.

introducing combined function bending magnets, the beam emittance could be reduced by a factor of 2. This upgrade would make UVSOR-II the world brightest low energy synchrotron light source. Other possibilities on the future plan are also under investigation, which include a ultra-low emittance storage ring, a linac-based free electron laser or an energy recovery linac.

2. Light Source Developments

A resonator-type free electron laser is operational at UVSOR. The wavelength is ranging from 800 nm to 199 nm and the average power exceeds 1W in visible and deep UV regions. In these years, it is used for users experiments[2] and for basic researches on free electron laser physics. In the latter, coherent photon seeding was successfully demonstrated,[3] in which a small fraction of the out-coupled laser light was re-injected to the optical cavity and the laser oscillation was drastically stabilized.

By utilizing the free electron laser optical cavity, we have developed a system to create micro-density structure on electron bunches circulating in the storage ring by using an external laser source.[4] By controlling the laser pulse shape, we can create various density structures such as a short dip structure or a periodic structure. In the former case, broadband coherent terahertz radiation was produced4). In the latter case, quasi-monochromatic coherent terahertz radiation was produced.[5] Such a micro-density structure normally disappears very quickly after a few revolutions of the electron bunch in the storage ring, which is due to the synchrotron motion. Thus, the intense terahertz radiation also stops. To suppress this effect and maintain the terahertz radiation for a long period, we tried to operate the ring with a small momentum compaction factor. It was observed that the terahertz emission lasted for about ten revolutions. It was also observed that the THz intensity drastically changed revolution by revolution. This peculiar behavior could be explained by the coupling between the longitudinal motion and the transverse motion of the electrons.[6]

Coherent harmonic generation is a method to produce coherent harmonics of laser light by using relativistic electron beam. The laser-electron interaction in an undulator produces density modulation of a period of the laser wavelength, which also contains harmonic components. Such an electron bunch radiates coherently at the harmonics of the injected laser. We have successfully observed the coherent harmonics of Ti:Sa laser in the VUV range, up to 9th harmonic.[7]

The coherent radiation experiments using laser is supported by the Quantum Beam Technology Program of JST/MEXT. Under this support, a part of the storage ring was reconstructed as described above and a new undulator will be installed. The upgrade of the laser system was completed. Two new beamlines dedicated to the coherent lights in the VUV range and in the THz range will be constructed.

Laser Compton scattering is a technique to produce a quasi-monochromatic X-rays and gamma-rays by using a relativistic electron beam and laser. The laser photons are Compton back scattered by the high energy electrons and are converted to gamma-rays. We have successfully demonstrated that the energy of the gamma-rays could be changed continuously by changing the injection angle of the laser. It was expected that a femto-second gamma-ray pulses could be produced by injecting the laser from the vertical direction to the electron beam. The experiment is under going.

3. Developments of Accelerator Technologies

Beam diagnostic systems are important especially during the commissioning of a new storage ring or that just after a big reconstruction. In collaborating with Synchrotron Radiation Research Center in Nagoya University, we have developed a turn-by-turn beam position measurement system and a betatron tune measurement system. The former was to measure the beam position of the electron beam just after the injection. The electron orbit of each turn was successfully observed.[8] In the latter, betatron tunes of the booster synchrotron during the acceleration was successfully measured. A suppression of the betatron motion due to the non-linear magnetic field was successfully observed.[9]

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