FIRST LASING OF SCSS TEST ACCELERATOR

X-ray Free-Electron Lasers (XFEL) will enable atomic-resolution imaging with a femtosecond snapshot. Research on XFEL has competitively progressed in the United States, Europe, and Japan. In FY2006, the construction of XFEL machine was officially started by a joint project organization termed the "RIKEN-JASRI Joint Project for the SPring-8 XFEL." This five-year project (FY2006-FY2010) has been recognized as one of the key technologies of national importance in the 3rd Science and Technology Basic Plan. The Japanese XFEL aims to achieve excellent performance with a compact machine, which can drastically reduce construction cost and improve the reliability of machine operation. The novel design, which is composed of a low-emittance electron gun with a thermionic cathode, a multiple-stage bunch compression system, high-gradient normal-conducting C-band linacs, and short-period in-vacuum undulators [1], is significantly different from those seen in other FEL projects. Thus, the experimental verification of the concept prior to finalizing the XFEL design is a stringent subject.

The SCSS (SPring-8 Compact SASE Source) test accelerator was primarily designed to perform proof-of-principle experiments for FEL operation. The beam energy of the machine is E_B = 250 MeV, which is only 1/32 that of the XFEL machine, E_B = 8 GeV. However, the test accelerator includes all basic components planned for the 8-GeV machine (Fig. 1). Following the construction and the observation of the first spontaneous light in 2005, we intensively conducted machine tuning to achieve lasing condition from May to July of 2006.

FEL accelerators should generate a high-density electron beam in both space and time. The performance is characterized by a normalized slice emittance ε_n and a peak current I_p. The target values are $\varepsilon_n \sim 1\ \pi$ mm•mrad and $I_p \sim$ kA, although the achievement of both criteria is a technical challenge. For this purpose, we have designed an injector system that combines a low-emittance electron gun with an adiabatic bunch compression system; the bunch length gradually decreases (i.e., peak current increases) as beam energy is boosted. This scheme is planned to suppress the space charge force, which can degrade the original emittance at the gun in the low-energy high-density electrons. The first target of the machine tuning is the verification of emittance preservation in compression.

The electron beam with a small emittance ($\varepsilon_n = 0.6\ \pi$ mm•mrad) is launched from a 500-kV pulsed electron gun equipped with a CeB$_6$ thermionic cathode ($E_B \sim$ 500 keV, $I_p \sim$ 1 A, pulse width $\tau \sim$ 2 microsecond) [2]. The beam is transmitted in a beam deflector ($\tau \sim$ 1 nanosecond), and is gradually compressed and accelerated with a 238-MHz pre-buncher cavity, a 476-MHz booster cavity, S-band linacs, and a magnetic chicane. At the end of this injector section,

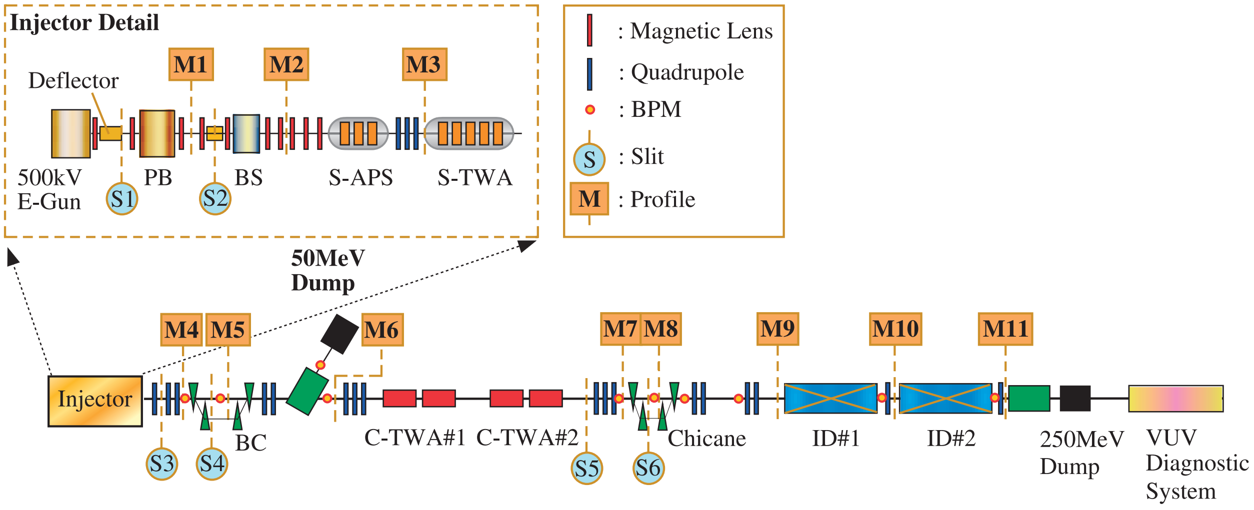

Fig. 1. Schematic layout of SCSS test accelerator.

the beam energy is boosted up to E_B ~ 40 MeV at I_p ~ 800 A and τ ~ 0.7 picoseconds. To maintain the original emittance we have to avoid over-focusing and over-bunching resulting in an emittance increase. Thus, we have carefully checked the beam property by beam profile and bunch length monitors, and optimized focusing and compression strengths.

The beam projected emittance at the exit of the injector section has been measured by a conventional Q-scan method, which monitors the response of the focusing strength of the quadropole magnet to the beam size (Fig. 2). The measured emittance of 3 π mm•mrad in the horizontal (3 π mm•mrad in the vertical) directions is in accordance with the simulated value of 2.8 π mm•mrad (2.6 π mm•mrad). We have experimentally confirmed the suppression of emittance growth in the compression scheme [3].

The electron beam is further accelerated with C-band linacs up to E_B = 250 MeV, and transported into in-vacuum undulators which modulate the trajectory of the electron beam by periodic magnets (15-mm period with a periodic number of 600) to produce short-wavelength radiation in the forward direction. When a small emittance and a large peak current of the electron beam are achieved, the power of the photon beam is dramatically enhanced owing to the efficient exchange of energies between electrons and photons. This lasing condition is characterized by diagnosing the photon beam properties.

On June 20, 2006, we observed the first lasing just after starting the commissioning of the undulator. Figure 3 shows the typical energy spectra of the laser and the usual spontaneous radiation with an electron beam charge of 0.25 nC and an undulator K-value of 1.3. A 6,000-fold amplification at a wavelength of λ = 49 nm was observed. The peak current of the electron beam is estimated to be I_p ~ 1 kA from a systematic study of the gain dependence on undulator K-values [3].

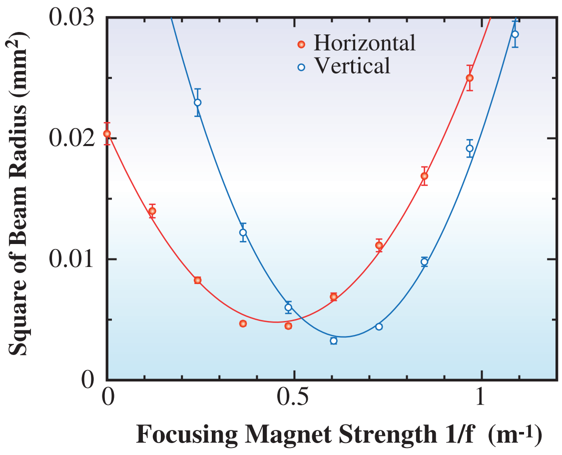

Fig. 2. Emittance measurement at exit of the injector.

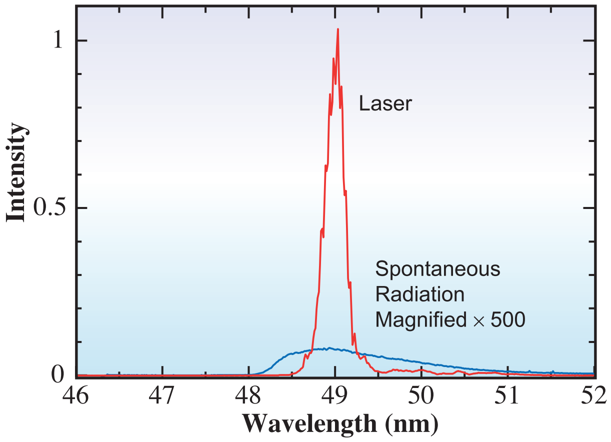

Fig. 3. Energy spectra of laser and spontaneous radiation.

The photon beam properties (a variable wavelength of $\lambda \geq$ 49 nm, a bandwidth of 0.4%, a pulse energy of a few μJ, and a pulse width smaller than 100 fs [4]) is prominent among vacuum ultraviolet (VUV) sources. We are planning to construct a VUV experimental station for public use in 2007. This machine will play crucial roles not only as a 'test' accelerator for studying FEL technologies but also as a 'practical' light source for developing novel scientific applications with intense VUV radiation.

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