STATUS OF X-RAY FEL/SPRING-8 MACHINE CONSTRUCTION

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Abstract

The XFEL/SPring-8 project has been funded in FY2006, which is aiming at generating 1 Å coherent intense X-ray laser using 8 GeV electron beam from the newly constructing normal-conducting C-band accelerator. The construction period is scheduled 2006-2010, and FEL operation will start in 2011. XFEL/SPring-8 is based on unique concept of SCSS: SPring-8 Compact SASE Source, while it requires low emittance and high peak current electron beam, i.e., normalized emittance of 1 π.mm.mrad and 3 kA peak current. We decided to employ the thermionic electron gun, which generates 1 A beam from single crystal cathode, followed by the multi-staged bunching system to achieve 3000 times compression. The design is based on the "Adiabatic Bunch Compression" scheme, i.e., compressing bunch length as inversely proportional to the beam energy, thus the bunch length on electron rest frame is kept constant, and as a result the low slice emittance is preserved. During 2006 ~ 2008, engineering design of the all hardware component have been completed and they are now in mass production. The facility construction is going on schedule.

INTRODUCTION

We started SCSS project in 2001[1,2] for developing technology required for X-ray FEL. SCSS stands for SPring-8 Compact SASE Source. By means of in-vacuum type short period undulator, the required electron beam energy can be made lower, additionally the C-band accelerator drives the beam at high gradient as high as 35 MV/m, as a result, the total system length becomes "compact", and it fits to available site length at SPring-8.

In the course of SCSS R&D, we developed the low emittance electron gun using single crystal CeB_6 cathode[3] and injector system which compress the bunch length by velocity bunching. We accelerate the electron beam energy as proportional to the increasing peak beam current, thus the space charge force is compensated, and preserve the small emittance from the single crystal cathode.

In order to verify this concept, we constructed the SCSS test accelerator in 2004~2005, and achieved the first lasing in June 2006 at 49 nm[4]. After hardware improvements on various components, including replacement of the undulator magnet due to its large magnetic field error, the SCSS test accelerator reached its FEL saturation in summer 2007[5]. From the gain and peak current measurements, the emittance in the undulator section was determined as 0.7 π.mm.mrad normalized, which is better than what we expected from the computer simulations.

Based on this experimental result, we designed beam optics in 8 GeV XFEL machine as shown in Fig. 2. The bunch length will be compressed in five stages; velocity bunching at gun to L-band accelerator, BC-1 (chicane bunch compressor), BC-2 and BC-3. Total compression factor is close to 4000, and peak beam current exceeds 3 kA in the undulator, which will satisfy the SASE-FEL lasing condition at 1 Å within 80 m long undulator line.

The undulator hall has been designed to install 5 beam lines. At the initial phase of the project, the BL3 (Hard X-ray Beam Line) will be constructed. BL-1 will be used as

Figure 1: The XFEL construction at Spring-8 site (May 2008). The 400 m long accelerator (from left to middle), followed by the undulator hall. The construction will be completed in 2009.

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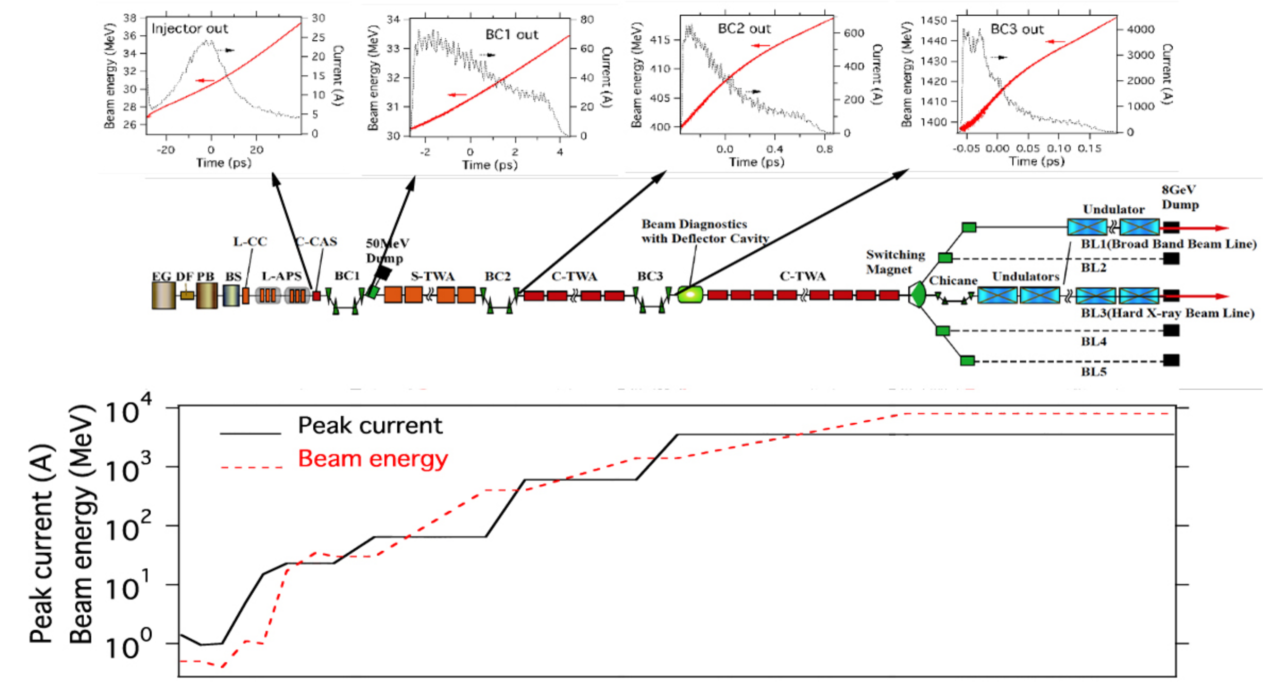

Figure 2: Machine configuration and beam current v.s. energy profile along the accelerator. Three chicane bunch compressors will be implemented, where the peak current will be increased step-by-step as proportional to the beam energy increase.

a bypass line for the beam commissioning.

Table-1 summarizes the beam parameters in the SCSS test accelerator and 8 GeV XFEL machine.

MACHINE CONFIGURATION

Figure 2 shows the machine configuration. Special care was taken in the design of 8 GeV machine to make linear the beam phase-space in the (z, E) phase space. Overlapping the higher order harmonic field on the dominant rf-field, we may flatten the effective acceleration field. This technique was implemented in the design at the 476 MHz booster cavity with L-band correction cavity and L-band accelerator with C-band correction cavity.

The frequency of the rf acceleration is designed as lower in the injector and gradually raised higher in the following accelerator. This is a part of the "Adiabatic Bunch Compression" scheme, where the wavelength of the rf field is designed to match the bunch length.

We have decided to use normal conducting linear accelerator technology at C-band frequency (5712 MHz) in the main linear accelerator. This technology was originally developed at KEK for the e+e- linear collider project. It is "warm" technology, not super conducting "cold" technology; therefore it can be constructed with lower cost. The C-band accelerator is capable of running at high accelerating gradient, as high as 35 MV/m.

Recently, we stated operate one of the C-band system in SCSS test accelerator at 36.6 MV/m (refer to Fig. 3). After two months operation, mostly for user beam time, so far we do not observe any hardware problems and high voltage break down inside the C-band accelerator (trip rate is less than one per day). This is quite promising for the 8 GeV machine, where 64 C-band klystron of 50 MW peak power and 128 C-band accelerators have to be operated safely.

All of the C-band hardware components were design to meet the original demands for e+e- linear collider, where special care was taken to ensure long life operation and high reliability. For example, the output section of the pulse compressor was carefully designed to avoid HV break down in copper structure of irises or ceramic material in the rf monitoring port, since the out put power exceeds 200 MW. So far no evidence of break down has been observed at the compressor, and the X-ray radiation level is still quite low.

Table 1. Machine parameter of XFEL/SPring-8

E-Beam Energy E	8	GeV
X-ray Wavelength l	3 ~ 0.1	nm
Emittance Normalized e_n	0.7	π.mm.mrad
Bunch Length	50	fsec
Peak Current	4000	A
Bunch Charge	0.2	nC
Machine Repetition	60	Hz
Maximum Bunch Per Pulse	50	Bunches
Maximum X-ray Pulse	3000	pps
Optical Output Power at 1 Å	0.4	mJ/pulse
Peak Photon Flux at 1 Å	2 x 10^{11}	photon/pulse
Peak Brightness at 1 Å	1 x 10^{33}	photons/mm^2 /mrad^2/0.1%BW

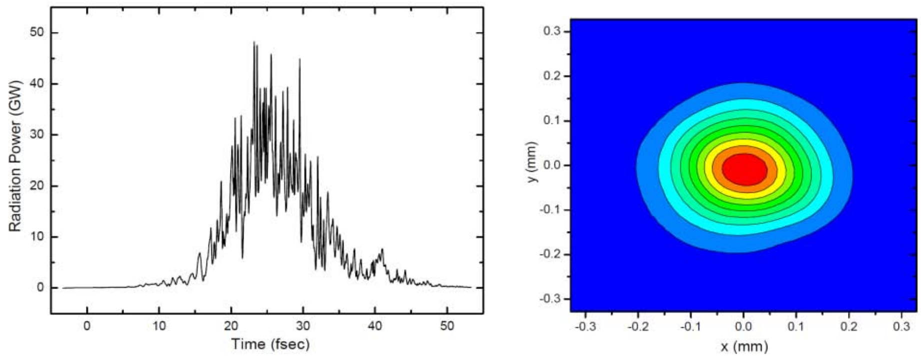

Figure 3: Simulated XFEL beam output at 1 Å. (left) Temporal intensity variation, FWHM is 20 fsec in this case. (right) cross-sectional X-ray intensity profile at 50 m downstream from the undulator (SIMPLEX simulations).

In the C-band accelerator, SiC microwave absorbers are implemented to damp the higher order modes[6]. XFEL/SPring-8 accelerator is capable of accelerating multi-bunch beam up to 50 bunches per pulse at 60 pps. The maximum X-ray pulse frequency is 3000 pulse per second. This unique feature will enhance the probability of X-ray collision to single bio-molecular in gas jet target in single molecular imaging experiment.

UNDULATOR

We use in-vacuum-undulator, whose magnet array is hybrid type consist from permanent magnet and iron yoke of 18 mm period. It is in-vacuum design with variable gap (2 mm ~ 40 mm). Nominal operation point is gap = 4 mm and K = 1.9. One advantage to use in vacuum undulator is that we have fairly wide beam aperture by opening the gap to 40 mm, where we can transport guide laser beam for alignment of cavity BPMs. Temperature control of the permanent magnet is one of the most important issue in precise undulator design, in this point the in-vacuum-undulator design provides ideal heat isolation from the environmental temperature change.

Figure 3 shows a simulation result on the SASE-FEL amplification with nominal beam parameter. It predicted that the FEL will be saturated within 120 m long undulator line. The estimated saturation power is 2 GW.

CONCLUSION & SCHDULE

Our design concept on low emittance electron gun and injector, based on thermionic cathode and adiabatic bunch compression, has been proven at SCSS prototype accelerator. XFEL/Spring-8 aiming at generating 1 Å X-ray was designed and its construction has been started in FY2006. The construction will be completed in FY2010 and the first X-ray beam test is scheduled in the end of FY2010.

REFERENCES

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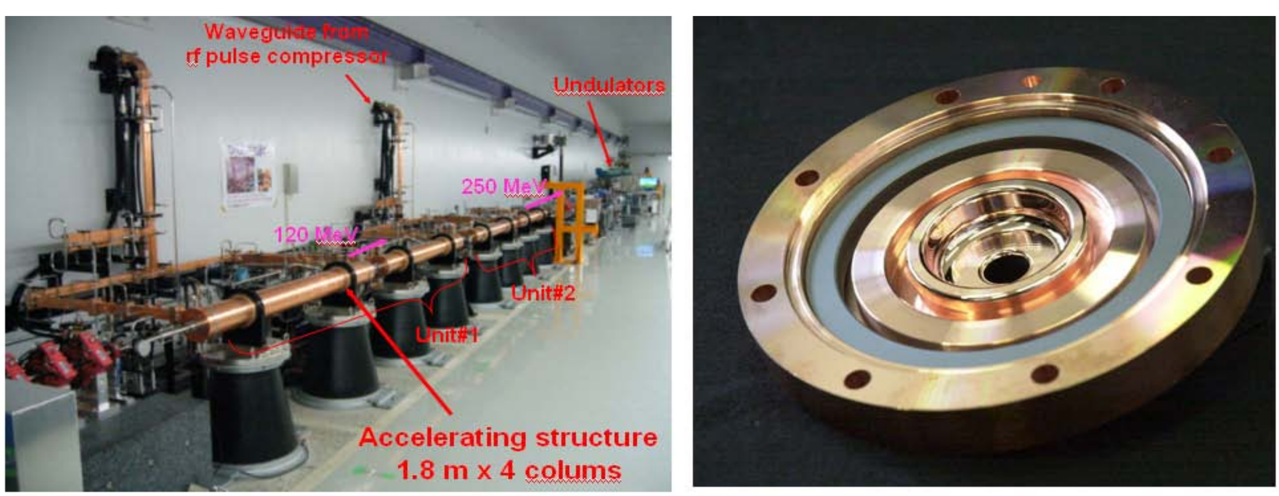

Figure 4: (left) Four C-band accelerating structures are installed in the SCSS test accelerator. Two of them are running at 36.6 MV/m in daily operation, providing beams for user experiments. (right) C-band accelerating structure is made by 92 cells made by OFC copper. The black coloured ring is SiC, which absorbs higher order modes excited by passing electron bunches, which enables low-emittance multi-bunch beam acceleration..