C-BAND LINAC IN SCSS PROTOTYPE ACCELERATOR OF THE JAPANESE X-FEL PROJECT

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Abstract

C-band (5712-MHz) linac is used as the main accelerator of the Japanese X-ray free electron laser (XFEL) facility in SPring-8. Since the C-band linac has high acceleration gradient, our 8-GeV accelerator is compact. One C-band unit consists of following components; two choke-mode-type 1.8-m accelerating structures, an rf pulse compressor, a 50-MW klystron, and a 110-MW compact modulator power supply. We will use 64 units of them for the X-FEL accelerator. Since November 2005, we have operated two C-band units in the SCSS (SPring-8 Compact SASE Source) 250-MeV accelerator. After rf conditioning, the accelerating gradient was achieved to 35-MV/m. We successfully accelerated the electron beam by this gradient of electrical field.

8-GeV LINAC FOR X-FEL

C-band (5712-MHz) linac is one of the key technology for the single-pass X-ray free electron laser (XFEL) project in SPring-8 [1]. The C-band linac generates high acceleration gradient (35-MV/m). It enables us to construct a "compact" 8-GeV linac with 230-m active length. Total length of the 1-angstrom FEL facility is 700-m. This is suitable size for our site.

Figure 1 shows the accelerator layout. After the injector and S-band section, first C-band section with 12 klystron units (24 accelerating structures) accelerate electron beam from 450-MeV to 1.5-GeV. At this section, the rf phase is set at 42-degree from the crest, in order to make energy chirp for the bunch compression chicane (BC2). After BC2, 52 C-band units (104 accelerating structures) accelerate the beam to 8-GeV with crest rf phase. Table 1 summarises the number of accelerator components.

Figure 2 shows one unit of the C-band accelerator system. RF source is a 50-MW pulse klystron. An rf pulse compressor compresses 2.5-μs square pulse to 0.5-μs pulse. It is fed to two 1.8-m accelerating structures. Repetition cycle is 60-Hz, which is synchronized to AC power line.

In order to supply stable FEL light to users, the accelerator should be absolutely stable. It is because the stability of the beam acceleration rf field directly affected to the stability of the photon energy. In addition, it also affected to the stability of the electron density after the bunch compression, and the stability of the beam trajectory. According to the beam optics consideration, stability of the acceleration energy of each unit should be order of 10^{-4}. For this ultra-high stability requirement, we have been made many efforts to the development of ultra-stable, low-noise modulator system and rf system. Long-

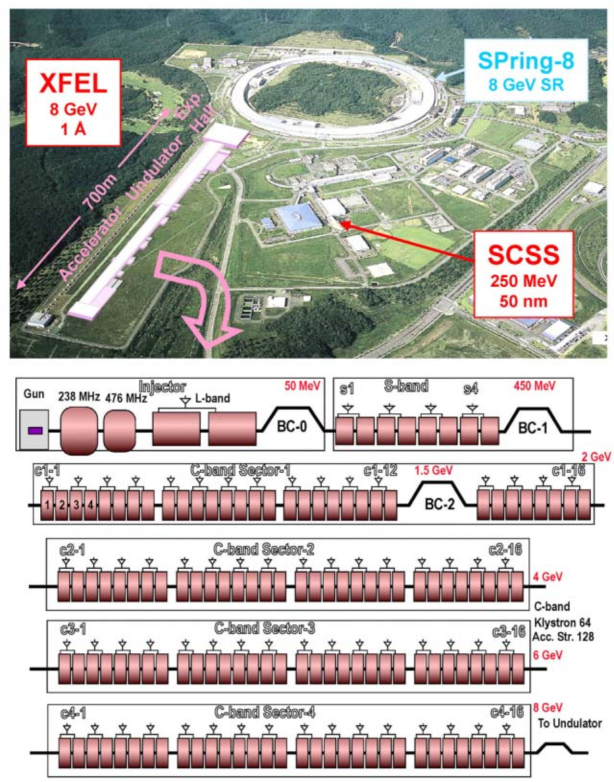

Figure 1: Computer Image of XFEL facility in SPring-8 site, and rf acceleration design of XFEL .

Table 1: Summary of the C-band linac for XFEL/SPring-8 and SCSS prototype accelerator.

	XFEL	SCSS
Accelerating structure	128	4
Klystron + Modulator	64 units	2 units
Acceleraton gradient	35 MV/m	28 MV/m (→35 MV/m)
Active length	230 m	7.2 m
Energy at end	8 GeV	250 MeV
Comissioning start	FY2010 (plan)	2005

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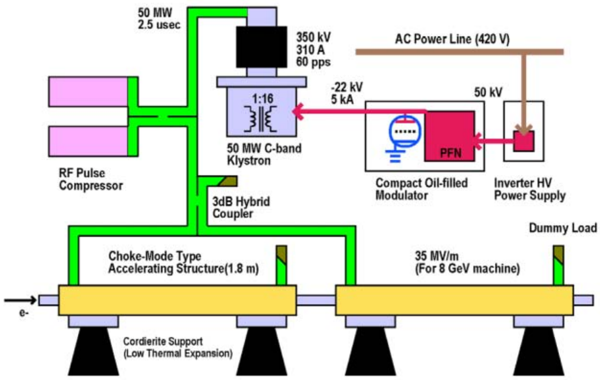

Figure 2: C-band accelerator system.

term reliability and maintenability are also very important for practical use as the coherent light source facility.

C-band accelerator was originally developed at KEK for e^+e^- linear collider. First model of the accelerating structure, the klystron, waveguide components, and first model of the rf pulse compressor are developed at KEK since 1995 [2,3]. These developments enable us to use the C-band accelerator system for XFEL. XFEL is the first practical use of the C-band accelerator.

SCSS 250-MEV ACCELERATOR

In order to demonstrate SASE-FEL, and to supply EUV coherent light to users, SCSS (SPring-8 Compact SASE Source) project was started in 2004 [1]. SCSS 250-MeV accelerator facility consists of the injector, two C-band units (named CB1 and CB2), and two undulators in 60-m length. First, we built the accelerator tunnel in the existing assembly hall. Civil construction was finished in August 2005. Then, we installed the accelerator components in very tight schedule. The first beam commissioning was started in November. After the careful beam commissioning, we successfully observed SASE amplification at 49-nm wavelength with 250-MeV beam energy in June 2006.

Another purpose of SCSS accelerator is the long-term performance test of many "new" accelerator components used in XFEL, which includes most of C-band components. In following section, performance of each component is explained with photos.

Choke-mode-type accelerating structure

Figure 3 shows the C-band accelerator section. Four 1.8-m accelerating structures are used. They are 91 cell quasi-CG structures. RF mode is $3\pi/4$ traveling wave. Shunt impedance is 54 MΩ/m in average. Attenuation parameter is 0.53. Filling time is 300-nsec. Unique feature is "choke-mode-structure". It eliminates the wakefield of the electron beam for future multi-bunch operation[2]. Fabrication of this accelerating structure is well established by MITSUBISHI HEAVY INDUSTRIES [4].

Frequency is finally adjusted by the precise temperature control system [5]. Measuring the body temperature, the feedback system controls the water heater of the cooling

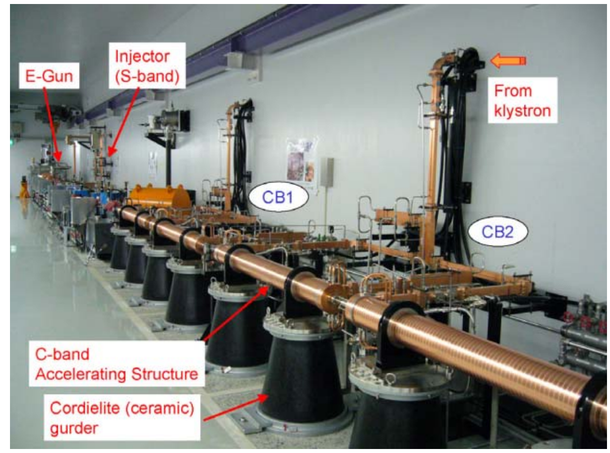

Figure 3: C-band accelerating structure in the tunnel.

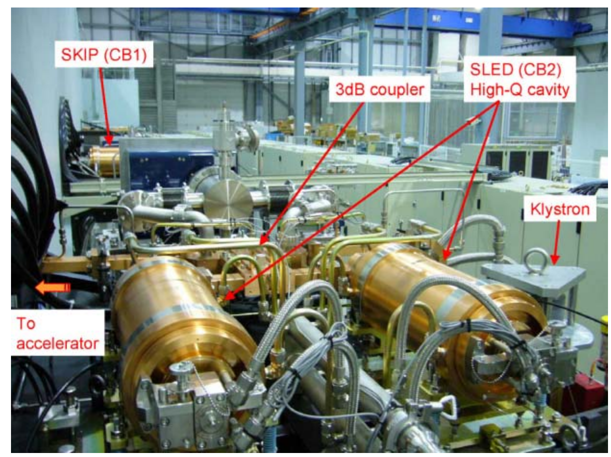

Figure 4: RF pulse compressor (SLED) at CB2.

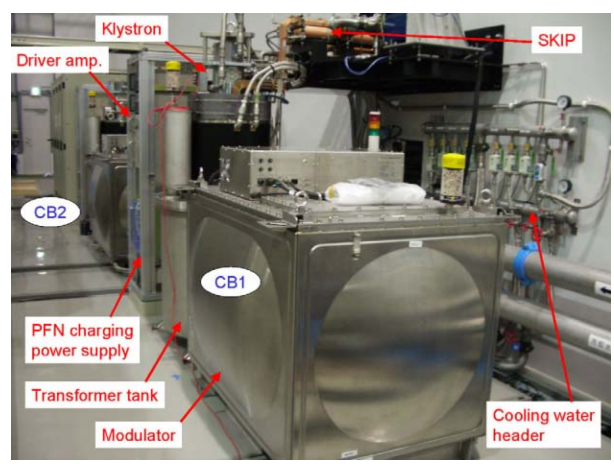

Figure 5: Modulators and klystrons.

water. After tuning of the feedback parameter, the temperature is always controlled within ±0.04 degree.

In usual operation, the acceleration gradient has been set at 28 MV/m, which is enough to obtain 250-MeV at end. Besides the operation, we did the rf processing in order to obtain higher acceleration field [6]. In the end of the 2006, after 500 hour processing, we obtained 35-MV/m. We performed the beam acceleration test and confirmed the gradient. At that time, rf discharge sometimes occurred. Further rf processing has been performed. Rate of the rf discharge is decreasing. So far we operated more than 1000 hour. We checked the inside of the structure. No damage has been observed. These progress and status are reported in [6].

RF pulse compressor

RF pulse compressor consists of one pair of high-Q cavities and one 3-dB coupler. In SCSS, we use two types of rf pulse compressors.

At CB2, SLED type pulse compressor is used. Figure 4 shows the outer view. RF mode of the cavity is $TE_{0,1,15}$. Measured Q_0 is 170,000, and β is 8.2. Unique feature is; each cavity has an rf mode converter [3]. It converts the waveguide mode (TE_{10}) to the cylindrical mode (TE_{01x}). For XFEL, we adopt this SLED type.

At CB1, we use $TE_{0,3,8}$ mode cavity, which is called SKIP. It is developed at KEK-PF/KEKB injector group [7]. Measured Q_0 is 130,000, and β is 6.3.

Both SLED and SKIP, practical power gain is almost same. Considering the average in 300-nsec filling time, The power gain is about 3.8. When we operate with high gradient, spike peak of output pulse sometimes causes the rf discharge. Therefore, we suppressed the peak with amplitude modulation [6]. This case, the power gain (300-nsec average) is about 3.

50-MW pulse klystron

Two klystrons (Toshiba E3746A) are used. So far, they have been working well over 1500 hours. We consider the fabrication [2] and the reliability are established.

Compact, oil-filled modulator

We developed 110-MW compact modulator [8]. Figure 6 shows the outer view of the modulator. In the SUS tank (1.7m×1.2m×1.2m), all the high voltage components, includes 18 series PFN, a thyratron tube, and reflected voltage clippers, are immersed in insulating oil. SUS tank works as the EM shield from the thyratron noise. The insulation oil prevents the trouble due to humidity or dust. Same modulator is also used for a S-band klystron and a DC gun. In total 4 modulators have been running without serious problem.

We use an inverter-type high voltage power supply for PFN charging. Maximum charging voltage is 50-kV. Averaged current is 1.5-A. Jitter of the charging voltage is one of the largest source of the acceleration energy stability. But it has been order of 10^{-3}. Last year, Shintake and one of the maker NICHICON improved the voltage stability. They added a precise power supply in parallel, and carefully tuned the voltage feedback. The voltage jitter is improved to 10^{-4} (100ppm). This stability is acceptable level for the XFEL. We have a plan to install next “completed-type” charging power supply, and to perform the long run test.

SUMMARY AND PLAN

Nominal acceleration gradient of 35-MV/m was achieved at SCSS C-band accelerator. We considered the accelerating structure and rf pulse compressor withstand such a high power rf field after reasonable rf processing. Klystron works well. Designs of these components are fixed. We started mass production of them for XFEL.

Remaining task is; pursue of 10^{-4} stability. We have making effort to improve the power supply. After careful check of the performance and the reliability, we should go to mass-production.

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