CONSTRUCTION STATUS OF C-BAND MAIN ACCELERATOR FOR XFEL/SPring-8

T. Inagaki[#], T. Sakurai, K. Shirasawa, C. Kondo, H. Maesaka, N. Adumi,
T. Hasegawa, S. Matsui, H. Kimura, N. Kumagai, and T. Shintake
Joint-project for XFEL/SPring-8, RIKEN and JASRI, Hyogo, Japan

Abstract

A C-band (5712 MHz) accelerator is employed as the main accelerator of the XFEL in SPring-8. The mass-production of the 64 units of the accelerator components has been completed. The production quality was confirmed by a high power rf test. The installation of the C-band accelerator components started in August 2009. Currently we almost complete the installation on schedule.

INTRODUCTION

A C-band accelerator is employed as the main accelerator of the X-ray free-electron laser (XFEL) facility in SPring-8 [1]. The frequency of the C-band accelerator is 5712 MHz, which is the double of a conventional S-band accelerator frequency. The higher frequency is chosen because the higher power efficiency can be obtained, which makes the accelerator compact. Since the C-band accelerator has a high acceleration gradient of 35 MV/m, the total length of the accelerator is fitted within 400 m, including the injector and three bunch compressors. This compactness is necessary to construct the XFEL facility in the SPring-8 site, and to save the construction cost. A normal conducting rf technology is employed for the C-band accelerator. It runs in the pulse mode at 60 pps, which is well suited for the XFEL operation.

MASS-PRODUCTION OF THE HIGH POWER RF COMPONENTS

Figure 1 shows one unit of the C-band accelerator system. The high power rf source is the 50 MW pulse klystron. The rf pulse compressor condenses a 50 MW, 2.5 μs square pulse to a 150 MW, 0.5 μs pulse, which is fed in two accelerating structures. One unit accelerates the electron to 125 MeV. We have 64 C-band accelerator units in order to obtain an 8 GeV electron beam.

The 1.8 m long accelerating structure is formed 91 cells, quasi-CG structure. The rf mode is $3\pi/4$ travelling wave. The shunt impedance is 54 MΩ/m on average. The attenuation parameter is 0.53. The filling time is 300 nsec. A unique feature is "choke-mode-structure". It eliminates the wakefield of electron beams for future multi-bunch operation [2]. Because of the choke-mode-structure, we could not tune the cavity frequency by a dimpling method. Therefore, the cavity cells were carefully shaped on a high-precision lathe, in order to adjust the cavity frequency. After rf measurements, they were brazed. The accelerating structures were fabricated by Mitsubishi Heavy Industries, Ltd. Thanks to the improvement on the lathe shaping and brazing, they steadily fabricated 128 accelerating structures. The cavity frequency was mostly matched between 5711.8 to 5712.0 MHz, and the square-averaged phase error was within 2 degrees [3]. These are the enough accuracy for XFEL.

The rf pulse compressor consists of one pair of high-Q cavities and one 3-dB coupler. The rf mode of the cavity is $TE_{0,1,15}$. The measured Q_0 is about 185,000, and β is about 9. Each cavity has a frequency tuner with a differential screw, which enables us to adjust the frequency to 5712 MHz ±10 kHz. The frequency adjustment is also important to minimize the reflection of the rf to the klystron. At the first model of the compressor, we experienced that the amount of the reflection changed after the evacuation of the cavity. We considered the end plate was slightly moved due to the small gap between the screws by the pressure of the atmosphere. Therefore we changed the screw tighter. Thanks to the improvement, 64 sets of the trf pulse compressor is stably adjusted. The VSWR is less than 1.05, which is small enough for the klystron. The rf pulse compressors and other waveguide components have also been fabricated by Mitsubishi Heavy Industries, Ltd. Further details are described in [3].

In order to confirm the quality, a high power rf test has been performed. We tested three different sets of these mass-produced components. We achieved the acceleration gradient of 40 MV/m without any problem. Further details are described in [4].

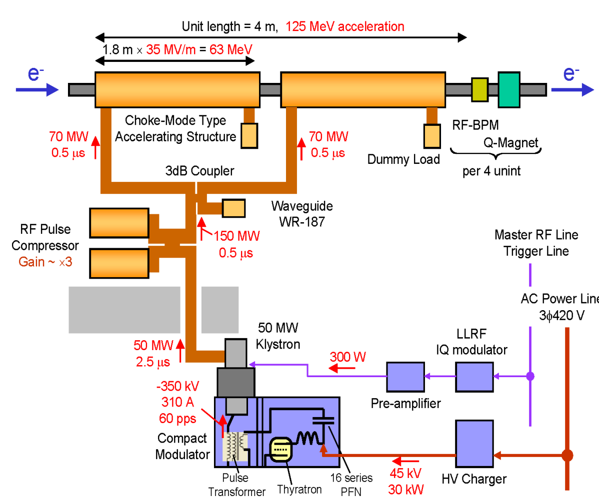

Figure 1: One unit of the C-band accelerator system.

[#]inagaki@spring8.or.jp

INSTALLATION IN THE TUNNEL

After the building construction has been completed in April 2009. We started the installation in August 2009. Figure 2 shows the procedure of the installation.

a) The 400 m long accelerator tunnel, before the installation.

b, c) We installed the rf pulse compressor unit on the wall using the crane. Since the rf pulse compressor was connected to the two accelerating structures and the klystron with the waveguide. Small tilt of the compressor made the large displacement of the waveguide at the end. Therefore, we carefully aligned the compressor with the accuracy of 1 mm.

d) We installed the accelerating structure. The accelerating structure was supported at the airy points of the structure, in order to minimize the natural bend

e, f) We carefully aligned the accelerating structures along the beam axis, using a laser tracker. Corner cube reflectors (CCR) were attached on the accelerating structure. The alignment accuracy was within 0.1 mm, which satisfied the requirement from the beam optics.

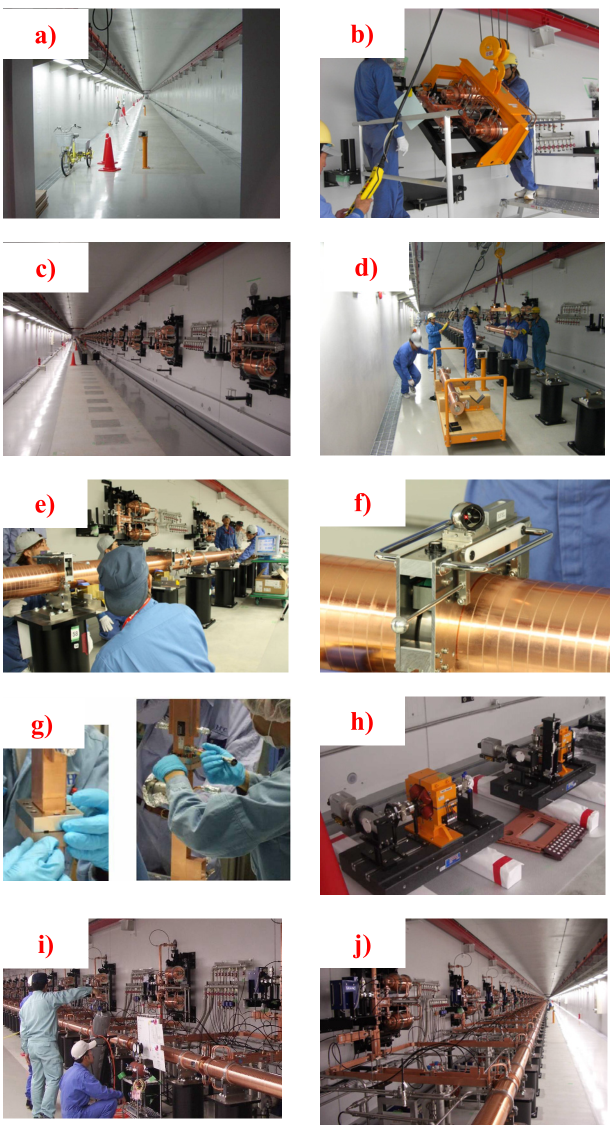

Figure 2: Installation of the C-band accelerator components in the tunnel.

g) We connected the waveguides. We employ ADESY-type flanges [5]. According to the suggestions from the previous study, we use DLC (diamond-like carbon) coated bolts. In addition, we managed the fastening torque (25 Nm) and the remaining gap (within 0.1 mm). Due to these careful managements, we experienced no leakage among 1000 of ADESY flange connections.

After the connection, a helium leak test was performed. We checked at a order of 10^{-11} Pa·m^3/sec, which was almost the detection limit of the detector.

h) A Q-magnet, a steering magnet, a gate valve, and beam monitors (an rf-BPM, and a screen monitor or a current monitor) [6] were assembled on the granite girder. They were installed between the accelerating structures. at intervals of 16 m.

i) A piping work of the cooling water was performed. We used 16 mm, 3/4 inch and 1 inch stainless steel tubes for the accelerating structure and the pulse compressor. Electrical heaters were installed between the inlet and the cavity for the precise control (stabilize) of the cavity temperature [7]. For the waveguide and the dummy load, nylon tube (8 mm) was used as the cost reduction. Photo i shows the 0.5 MPa pressurized test using a N_2 gas. We carefully checked with the liquid leak detector (snoop).

All of these installation works were done by the collaboration of IHI inspection & instrumentation Co. Ltd and us (installation & alignment team of XFEL project) Our collaboration works well. We started the installation of the main components in August 2009. Roughly, it took approximately one month to install 4 units per one team (5 or more workers). Two teams worked in parallel to install 64 units. Now (May 2010), we have almost completed the installation on schedule, without a serious problem.

MASS PRODUCTION AND INSTALLATION OF THE KLYSTRONS AND THE MODULATORS

C-band pulse klystrons (5712 MHz, 50 MW, 60 pps, [8]) have been manufactured by Toshiba Electron Tubes & Devices Co. Ltd. High power processing and the operation test was performed at the factory.

The compact modulators [9] have been manufactured by Nichicon Corporation. At the factory, high voltage operation test was performed with low repetition rate (~1 pps), using a resistance load instead of the klystron. After the delivery to XFEL, final operation test was performed.

Figure 3 shows the procedure of the installation of the klystron and the modulator.

k, l) At the assembly hall, the klystron was attached on the modulator. Then, the modulator tank was filled with the insulation oil. A special oil purifier [10] was used to improve the insulation and to remove floating dusts.

m) Final operation test was performed with the maximum voltage (~350kV) and a 60 pps repetition, without an rf input (diode operation of the klystron). We checked the waveforms, stabilities, temperatures and the trip rate during the 8 hours of the continuous operation.

n) When the klystron unit passed the test, it was moved to the klystron gallery using the special trailer and the crane.

o, p) The modulator equips three air-pad floaters under the tank. By supplying compressed air (~0.7 MPa) to the floaters, the modulator (weighted about 5 ton) was floated and was slid easily. We used them for the waveguide connection to the klystron. The yellow tool in photo o is the guide attachment. By rotating the handle of the attachment, the klystron gradually approaches to the waveguide.

The installation started in July 2009. In first several months, we suffered many troubles; i.e., thyratron noise, diode broken, high voltage breakdown, oil leak, … But, finally Nichicon and we (modulator team) overcame all the problems [9]. So far about 60 of the klystron units have been installed at the klystron gallery (see photo q).

A control system, a low-level rf system [11], and magnet power supplies are installed in a series of 19-inch racks. The precise high voltage charger has not been installed, because some modification works still remain. Hereafter we will carry out the cabling, cooing water piping, and the preparation of the control system.

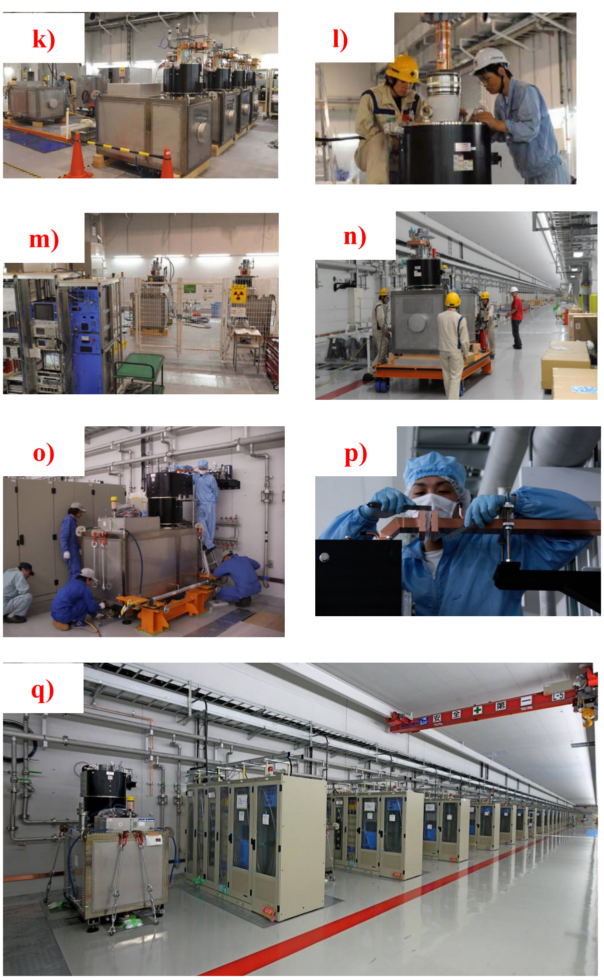

Figure 3: Installation of the klystrons and the modulators.

SUMMARY AND SCHEDULE

The 8 GeV C-band accelerator has been constructed in XFEL. 64 units of the accelerator components were produced at several companies in Japan, with sufficient qualities. Currently we have almost installed accelerator components, on schedule. In October, we plan to start the high-power rf commissioning. In the beginning of the next year, we will start the beam commissioning.

AKNOWLEDGEMENT

We thank Miura-san, Okihira-san, and Inoue-san in Mitsubishi Heavy Industries, Ltd. for the development of the accelerating structure and the rf pulse compressor. We also thank Rokuyama-san, Matsumoto-san, Kawaguchi-san in Nichicon Corporation for the production of the modulator. We thank Ushikubo-san and Kasahara-san in IHI inspection & instrumentation Co. Ltd. for the installation. And we thank to all of XFEL group members.

REFERENCES

[1] T. Shintake et. al., "SPring-8 Compact SASE Source (SCSS)", SPIE, Optics for Fourth-Generation X-ray Sources, Bellingham, August 2001, P. 12.
[2] T. Shintake et al., "The First Wakefield Test on the C-band Choke-mode Accelerating Structure", PAC'99, 1999.;
[3] K. Okihira, et. al., "Mass production of C-band rf pulse compressor", IPAC'10, 2010.
[4] T. Sakurai, et. al., "High power rf test on the mass-produced C-band rf components for XFEL/SPring-8", IPAC'10, 2010.
[5] T. Bizen, "Development of vacuum components for XFEL/SPring-8",EPAC'08, THPP137, p. 3682-3684, 2008.
[6] S. Matsubara, et. al., "Development and construction status of the beam diagnostic system for XFEL/SPring-8", IPAC'10, 2010.
[7] T. Hasegawa, et. al., "Status of precise temperature regulation system for C-band accelerator in XFEL/SPring-8", IPAC'10, 2010.
[8] Y. Ohkubo, et. al., "The C-band 50MW Klystron using Traveling-wave Output Structure", LINAC'98, 1998.
[9] T. Shintake, et. al., "Compact klystron modulator for XFEL/SPring-8", IPAC'10, 2010.
[10] http://www.katofl.com/
[11] N. Hosoda, et. al., "Construction of a timing and low-level rf system for XFEL/SPring-8", IPAC'10, 2010.