HIGH POWER TEST OF C-BAND ACCELERATING SYSTEM FOR JAPANESE XFEL PROJECT

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Abstract

The C-band (5712 MHz) accelerating system will be used as the main accelerator for the SPring-8 Compact SASE Source project. In order to confirm the performance of the C-band accelerator for the 8 GeV XFEL machine, the same accelerating structure and RF system have been installed in the SCSS prototype accelerator. A high power test of all the accelerator components has been performed. A 35 MV/m accelerating field was achieved during the beam test.

INTRODUCTION

The X-ray free electron laser (XFEL) is one of the next generation light source. In Japan, SPring-8 has a single-pass XFEL project, the SPring-8 Compact SASE Source (SCSS). This project uses a 8 GeV linac to generate 1 Å coherent intense X-ray laser. The construction will start in 2007: 128 C-band accelerating tubes and 64 klystrons will be installed as the main accelerator.

Since the C-band accelerator generates a higher accelerating gradient than the traditional S-band accelerator, the machine is more compact and the cost is lower. However, the C-band accelerator is a new technology for an electron linac. In order to check the performance of the developed hardware components and to prove SASE amplification, the prototype accelerator for the XFEL was constructed. After the beam commissioning, the first SASE amplification was observed at 49 nm in June 2006 [1].

In the prototype accelerator, four 1.8 m long C-band accelerating structures are used to accelerate electrons from 45 MeV to 250 MeV. Normal operation, the accelerating gradient of the C-band accelerator is 28 MV/m with the klystron output power of 27 MW.

On the other hand, the C-band accelerator for the 8 GeV linac is designed to operate with the field gradient of 35 MV/m. Therefore, the accelerating filed measurement has been performed after the high power test at the prototype machine.

SCSS C-BAND ACCELERATOR

The C-band accelerator consists of two units; each unit has one 50 MW klystron, pulse compressor and two accelerating structures. A schematic diagram of the C-band accelerator is shown in Fig. 1.

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Figure 2 shows the photograph of the C-band accelerator of the SCSS prototype machine. As shown in Fig. 1 and Fig 2, the stable support stands made from a low thermal expansion material, cordierite ceramic, are used for the accelerating structure [2]. Cordierite ceramic has a thermal expansion coefficient ten times lower than that of iron.

Klystron and HV Power Supply

The C-band klystron (Toshiba E3746A) [3] generates a maximum power of 50 MW with a pulse width of 2.5 μsec and a repetition rate of 60 Hz. In order to provide pulsed high voltage for the klystron, the inverter type high voltage power supply and the compact oil-filled modulator are used. [4]. The inverter type high voltage power supply charges the pulse forming network (PFN) circuit of the modulator. The charging voltage is 50 kV. A 1:16 step-up transformer is inserted between the PFN circuit and the klystron. Consequently, a pulsed high voltage of -350 kV is provided for the klystron.

C-band Choke-Mode Type Accelerating Structure

The first C-band choke-mode type accelerating structure was developed in 1998 for the linear collider project [5, 6]. A 1.8 m long structure was developed in 2002 for this project. The main parameters are listed in Table 1. The structure consists of 89 regular-cells with damping slots and input/output coupler-cells. In order to get enough space for the choke, the $3\pi/4$ mode was used. In this mode, the space which can be used for the choke is longer than in the conventional $2\pi/3$ mode by about 2mm. Therefore, this structure shows quite effective damping of HOMs over a wide frequency range. It makes possible to accelerate the multi-bunched beam with no wakefield instability [7].

Pulse Compressor

At the SCSS prototype machine, two types of pulse compressors, SKIP or SLED, has been adapted for research and development. The SKIP was developed by the KEK injector group [8]. On the other hand, the SLED was originally designed for linear collider [9]. Three-cavity design was introduced to improve energy efficiency. To make simple the system, the traditional SLED design (single cavity) has been chosen for the SCSS project. Parameters for each pulse compressors are listed in Table 2. The quality factor was measured with low level RF. The SKIP is installed on

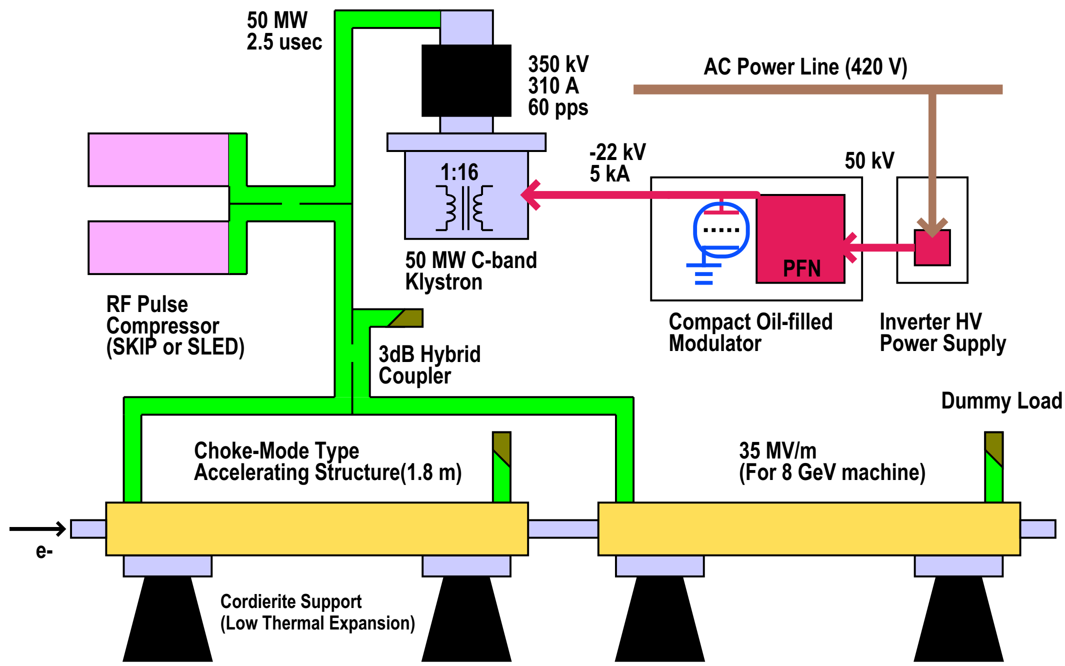

Figure 1: A schematic diagram of the C-band accelerator unit.

Table 1: Parameters of the C-band accelerating structure.

Frequency	5712 MHz
Phase shift per cell	$3\pi/4$
Field distribution	semi C.G.
Number of cells	89+2coupler cell
Active length	1791 mm
Disk thickness	4 mm
Q (measured)	10300$\sim$10700
Group velocity (measured average)	0.019c
Attenuation parameter (measured)	0.52$\sim$0.54
Filling time (measured)	308$\sim$309 nsec

the upstream C-band accelerator, and the SLED is downstream. Each power gain, which is estimated from measured Q_0 and β, is almost same. A RF power gain above 3 is required for the 8 GeV machine.

Table 2: Parameters of the pulse compressors

	SKIP	SLED
Frequency	5712 MHz	
Q_0 (measured)	130000	170000
Mode	TE038	TE01,15
β (measured)	6.3	8.2

HIGH POWER TEST

A high power test has been performed to confirm the stability and reliability of all the components: klystrons, pulse compressors, accelerating structures, dummy loads and HV power supplies. After a 500 hours RF processing, the klystron output power was reached to 44 MW. The repetition during the processing was 60 Hz. The RF pulse width was started from 0.1 μsec. Finally, it was expanded to nominal value of 2.5 μsec, while the pulse width before phase inversion was 2.0 μsec. The vacuum pressure is monitored by cold cathode gauges (CCGs). The CCGs are used as trip signals of klystron modulators during RF operation to protect the structure from a breakdown. We carefully increased the klystron output power with monitoring the vacuum pressure. During the processing, the vacuum pressure around the pulse compressor was higher than at the other points, namely around the accelerator tube and the dummy

Figure 2: A photograph of the C-band accelerator. This view is from the downstream of the C-band accelerator.

load. However, after the klystron output power reached 40 MW, the vacuum pressure was as low as the other points. The typical RF wave form is shown in Fig. 3. To avoid RF discharge in the accelerator tube, a sharp peak at phase inversion has been suppressed by RF amplitude modulation. The modulation is applied by the low level RF system [10].

BEAM ENERGY MEASUREMENT

In order to find the energy gain of the accelerating structure, the beam energy was measured by the chicane magnets located downstream of the C-band accelerator. The beam timing and RF phase were optimized to obtain the maximum beam energy. Figure 4 shows the measured accelerating gradient as a function of the klystron output power. The maximum gradient was 35 MV/m. It corresponds to an average input power of 62 MW which is estimated from the measured shunt impedance. The operational repetition was 10 Hz at the beam energy measurement. Assuming the RF loss between the klystron and accelerating structure is 13 %, the RF power gain of SKIP was 3.2. The RF discharge was sometimes observed at 35 MV/m, even though the stable operation was possible up to 34 MV/m. Additional RF processing is considered to be necessary for the 35 MV/m operation.

CONCLUSION

As the result of the beam energy measurement, the achieved accelerating gradient is 35 MV/m. In this gradient, the klystron output power is 44 MW. Practical operation with an accelerating gradient above 35 MV/m seems feasible after a reasonable processing time. Total operation time of the C-band accelerator exceeds 1000 hours until the end of 2006. No serious problem has been observed for all the accelerator components.

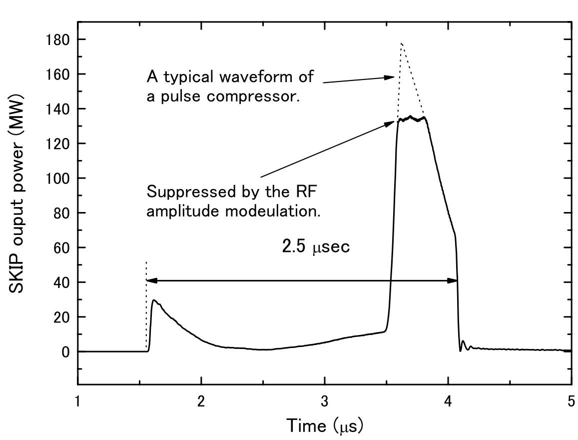

Figure 3: Typical RF waveform measured downstream of the SKIP. The klystron output was 42 MW.

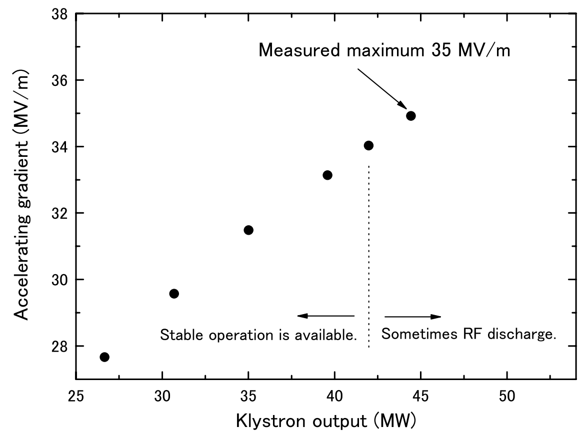

Figure 4: Measured accelerating gradient as a function of the klystron output power.

ACKNOWLEDGEMENT

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