HIGH GRADIENT TESTS 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 XFEL/SPring-8 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. The C-band accelerator performance has been investigated at the prototype machine.

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. This project uses a 8 GeV linac to generate 1 $\mathring{A}$ coherent intense X-ray laser light. 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. During 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 field measurement has been performed after the RF processing at the prototype machine.

C-BAND ACCELERATOR

In the prototype machine, the C-band accelerator consists of two units; each unit has one 50 MW klystron, a pulse compressor and two accelerating structures. A schematic diagram of the C-band accelerator is shown in Fig. 1. The C-band klystron (Toshiba E3746A) [2] generates a maximum power of 50 MW with a pulse width of 2.5 μsec and a repetition rate of 60 Hz. An inverter type high voltage power supply and a compact oil filled modulator are used to provide the pulsed high voltage to the klystron [3]. 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. Figure 2 shows the photograph of the C-band RF source of the prototype machine.

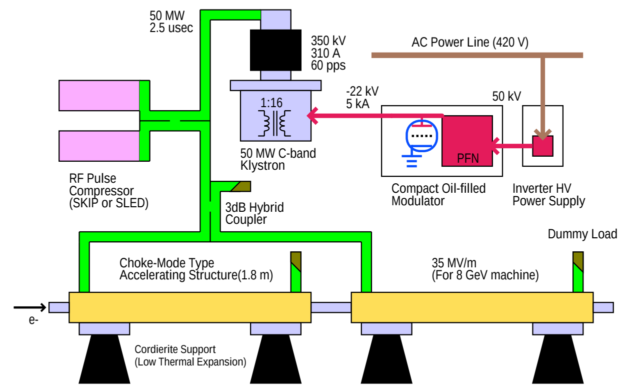

Figure 1: A schematic diagram of the C-band accelerator unit.

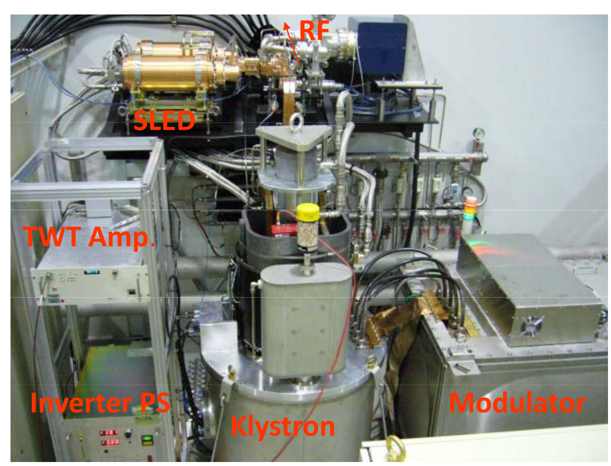

Figure 2: A photograph of the C-band RF source.

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 [4, 5]. A 1.8 m long structure was developed in 2002 for this

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project. 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 is 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 2 mm. This special RF cavity shows quite effective damping of HOMs over a wide frequency range. The RF power for the beam acceleration is kept within the main cavity by means of a choke-filter. It is therefore possible to accelerate the multi-bunched beam with no wakefield instability [6].

Pulse Compressor

At the SCSS prototype machine, two types of pulse compressors, SKIP or SLED, have been adapted for research and development. The SKIP was developed by the KEK injector group [7], while the SLED was originally designed for linear collider [8]. The three-cavity design was introduced to improve energy efficiency. However, to simplify the system, the traditional SLED design (single cavity) has been chosen for the XFEL project. The SKIP is installed on the upstream C-band accelerator, and the SLED is downstream. Each power gain, which is estimated from the measured Q_0 and β, is almost the same. A RF power gain above 3 is required for the 8 GeV machine.

HIGH GRADIENT TESTS

A high gradient 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.

RF Processing

The RF processing of the accelerating structures and pulse compressors was performed automatically by a computer program. Judging the level of the vacuum pressure, the program increases and decreases the klystron output power. The flow chart of the RF processing is shown in Fig 3.

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. 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 load. However, after the klystron output power reached 40 MW, the vacuum pressure was as low as the other points.

After a 500 hours RF processing, the klystron output power reached 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 SKIP RF waveform and the klystron beam voltage are shown in Fig. 4. To avoid damage to the accelerating structure, the sharp peak at phase inversion has been suppressed by RF amplitude modulation. The modulation is applied by the low level RF system [9].

Accelerating GradientMeasurement

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. 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.

Inside Investigation of theAccelerating Structure

After the accelerating gradient measurement, we investigated the inner surface of the accelerating structure. A borescope (OLYMPUS) was used to observe the iris edge in the accelerating tube. Fig. 5 (a) is a view from the upstream flange of the accelerating structure. Fig. 5 (b) is the iris edge taken by borescope. As shown in Fig. 5, no damage due to the RF discharge, was found on the inside

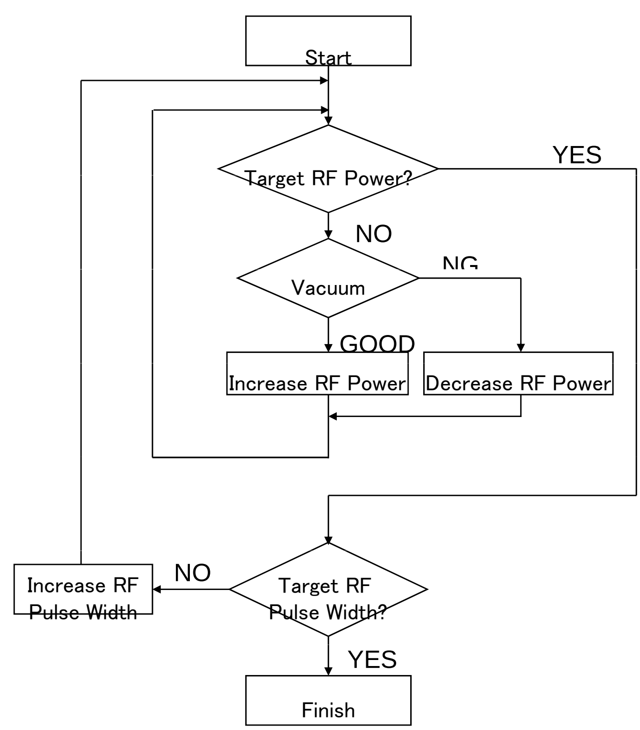

Figure 3: A flow chart of the RF processing. The RF power is controlled by changing the charging voltage of the inverter power supply.

surface. The small difference of the surface color shows the grain boundary of Cu. The total operation time of the C-band accelerator before this observation exceeds 1000 hours.

CONCLUSION

As the result of the beam energy measurement, the achieved accelerating gradient is 35 MV/m. At 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. Furthermore, we have investigated the inner surface of the accelerating structure. No damage was found on the inside surface of the accelerating tube. The performance obtained from the high gradient tests satisfies the XFEL/SPring-8 requirements. The 8 GeV accelerator construction has started in June 2007.

ACKNOWLEDGEMENT

The RF processing was performed with the help of many XFEL/SPring-8 members.

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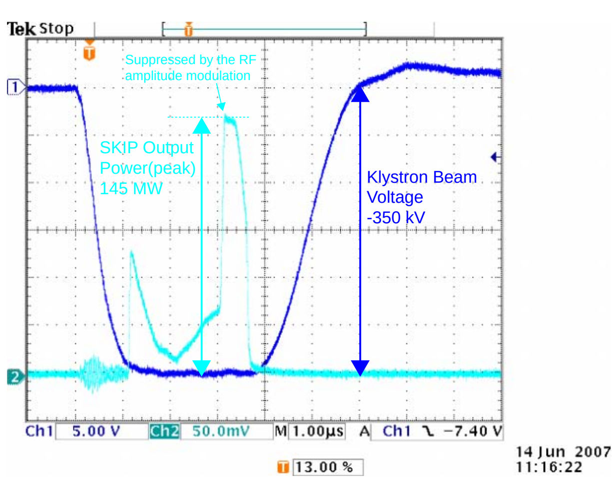

Figure 4: Ch1: RF output power from the SKIP. Ch2: Klystron beam voltage.

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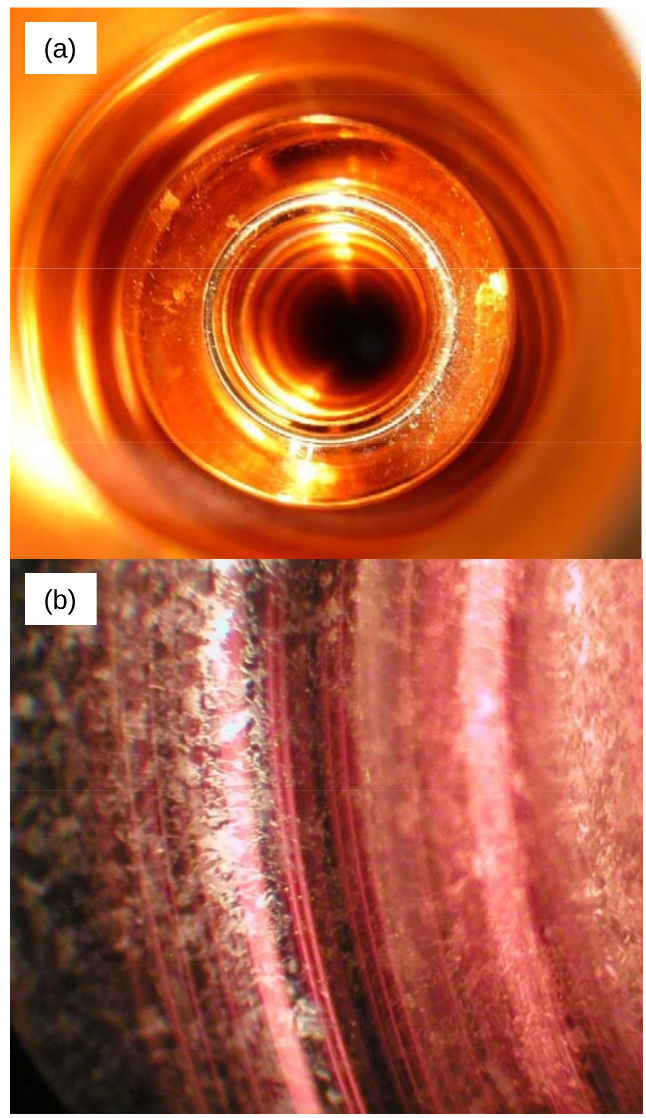

Figure 5: (a) Inside view of the C-band accelerating structure. (b) The upstream iris edge observed with the borescope. The small difference of the surface color shows the grain boundary of Cu.