RECENT PERFORMANCE OF THE JAERI SUPERCONDUCTING LINAC FOR FEL

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Abstract

Far-infrared FEL oscillation using the superconducting linac has succeeded in JAERI. The linac consists of a 250kV electron gun, a subharmonic normal-conducting buncher (SHB) of 83.3MHz, two single-cell and two 5-cell superconducting cavities of 499.8MHz. The gun was typically operated around 200 kV to reduce space charge effects.

The combination of the SHB and two single-cell cavities enabled high current beam of more than ten amperes by utilizing a thermionic cathode and a grid pulsing. Calculations utilizing the modified PARMELA code showed that the electron bunch of 3 ns from the electron gun was finally compressed to be 20-35 ps after the two single-cell cavities. FWHM bunch length and 80% emittance were measured to be 22ps and 35 pi mm mrad.

1 INTRODUCTION

Many kinds of free-electron laser (FEL) facilities exist in the world. Some are striving to develop a short wavelength FEL while others are trying to find applications in various fields, such as medical and scientific research. The purpose of the Japan Atomic Energy Research Institute (JAERI) FEL project is to develop a high-average-power, high-efficiency FEL for research and industrial use[1,2]. The stable FEL oscillation was achieved in March 1998. Figure 1 shows the schematic layout of JAERI superconducting linac. This paper describes the detail design of JAERI FEL linac and the measurement of bunch length and emittance.

2 CONCEPTUAL DESIGN OF THE JAERI FEL LINAC

The average power of an FEL is determined by multiplying the peak power by the repetition rate and pulse length. Thus, to create a high-average-power FEL, it is necessary to increase the peak power, the repetition rate, and the pulse length. The peak power is proportional to the peak current of the electron beam. The peak current of the linac is normally a few hundred amperes maximum for an RF linac. Though an RF gun and photocathode are used to obtain the high-current beam, it is difficult to

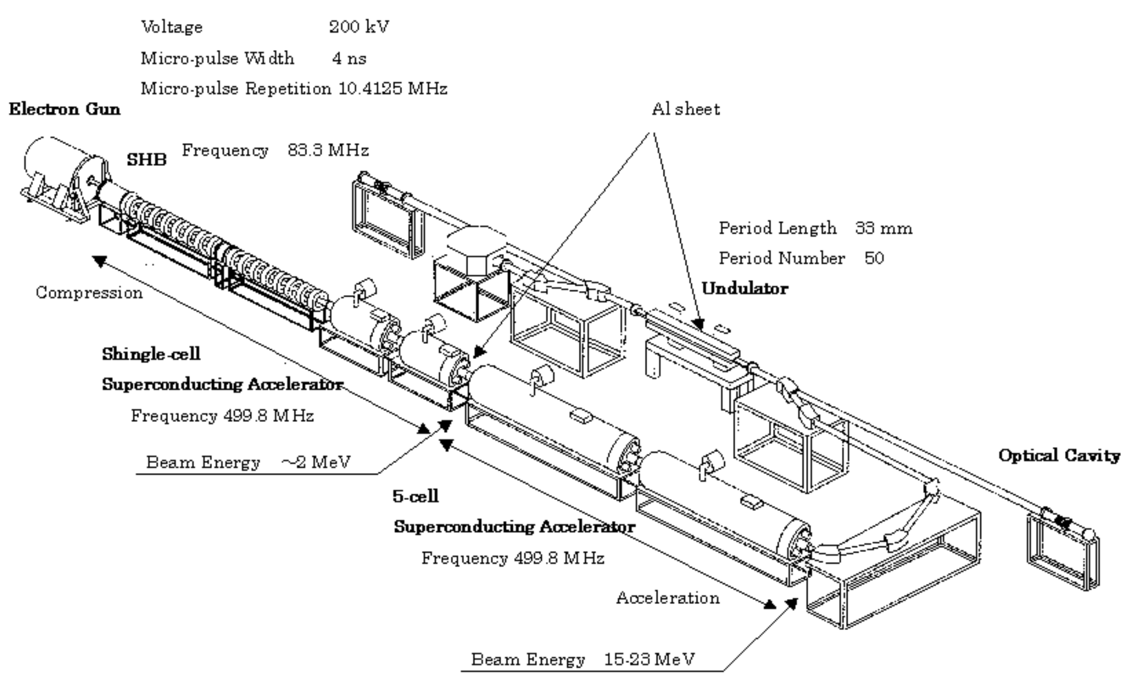

Figure 1: Schematic Layout of the JAERI Superconducting Linac

operate them with a high-repetition rate and a long pulse length. From this standpoint, a linac with a high repetition rate and a long-pulse or continuous-wave (CW) mode operation is suitable for a high-average-power FEL. Therefore, superconducting accelerators are superior.

The electron beam power is converted to laser power with an efficiency of only a few percent or less. When the electron beam is dumped, most electron beam power is wasted. Therefore the efficiency of an FEL is usually very low. Reusing the electron beam and reducing the RF loss increase the efficiency. Superconducting cavities have a very small RF power wall loss, which makes them superior to normal conducting cavities for a high-efficiency FEL linac.

Thus, we conclude that superconducting accelerators used as the main accelerating components are best to realize a high-power, high-efficiency FEL.

3 DESIGN DETAILS OF COMPRESSING SECTION OF THE JAERI FEL LINAC

For the electron gun, the thermionic cathode is the most acceptable choice presently available. However, it is difficult to obtain a high-current electron beam that has a current of more than a few hundred milliampere and also has good emittance. Therefore, a beam compressing system is necessary to produce a high-peak-current beam.

A frequency of 500 MHz was selected for the main accelerating components. A period of 500 MHz is 2 ns and at least half of that is unavailable for compressing the beam. Therefore, to compress the beam bunch of more than 1 nanosecond, a subharmonic buncher (SHB) is required. When the bunch length from the electron gun is 3-4 ns, the subharmonic frequency must be less than a quarter of the main frequency, 500 MHz. Though an SHB using lower subharmonics can compress a beam bunch to a shorter length than one using higher subharmonics, it requires a higher buncher voltage, which results in a larger RF loss in the SHB. Considering long-pulse or CW mode operation, low-power loss is desirable. We chose a subharmonic number of 6 for the SHB.

When the charge density increases by shortening the bunch length or when the beam current is originally high, beam compression with only the SHB does not work well because of the space charge effects. A means of resolving this problem is to install an additional element that works not only as a buncher but also as an accelerator that decreases the space charge force. Since we are considering a high-average-power, high-efficiency FEL, the accelerating section of the linac must be superconducting. If a multicell superconducting module is adopted for this element, it causes not only less effective acceleration but also an increase in the energy spread. When the phase in the first cell of a multicell is adjusted to enhance both compression and acceleration, the remaining cells are out of the phase of maximum accelerating. That causes an expansion of the energy spread because the accelerating field of the maximum accelerating phase has the smallest energy spread. Therefore, the multicell superconducting accelerator is unsuitable, whereas the single-cell element is suitable. Thus, two single-cell superconducting modules are installed after the SHB section to accelerate the beam to almost the speed of light.

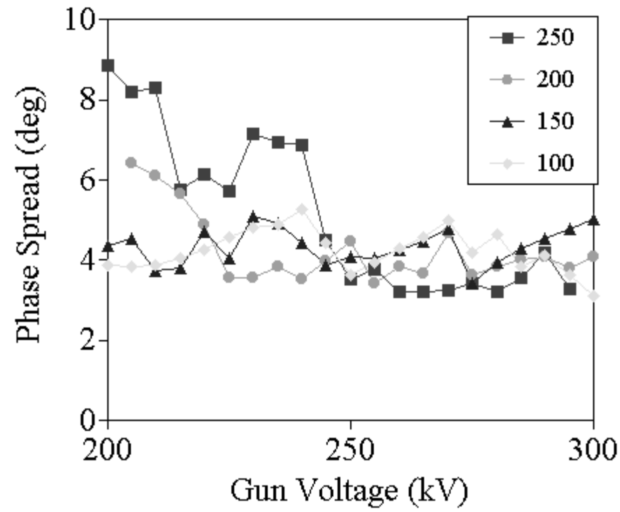

Figure 2: Calculated phase spread with different gun voltage and with different beam current.

The voltage of the electron gun influences the phase spread. Figure 2 shows the phase spread of the compressed bunch with the SHB and two single-cell cavities calculated with PARMELA. The initial phase spread was 3 ns. The 80 % phase spread was calculated by optimizing the phases of SHB and two single-cell cavities and the amplitude of SHB.

The figure shows that this compression system works well. For high beam current such as 200 mA and 250 mA, increasing the gun voltage has an advantage of making the beam spread small. For low beam current such as 100 mA and 150 mA, the phase spread does not change so much according to the gun voltage. Therefore, 200 kV gun voltage is sufficient for the beam current less than 150 mA.

4 MEASUREMENT OF THE BEAM BUNCH LENGTH AND EMITTANCE

The bunch length was measured at the middle of the undulator. The bunch length is estimated to be several tens picoseconds. The beam bunch length was measured with a steak camera made by Hamamatsu Photonics Co. An aluminum plate profile monitor was installed within the undulator duct. When the electron beam collided with an aluminum plate, optical transition radiation (OTR) was emitted. The bunch length was measured by detecting the OTR by the streak camera. Figure 3 shows the result of

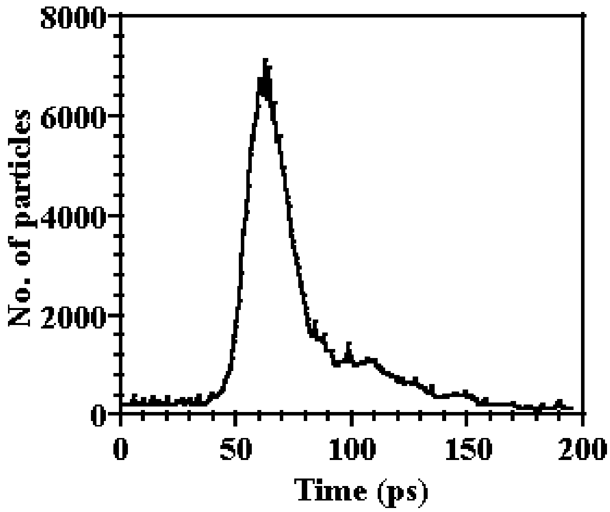

Figure3: Measured bunch length

the bunch length measurement. It indicates a bunch length of 22 ps, which corresponds to 4.0 degrees.

The beam eminence was measured by measuring the beam distribution on the profile monitor with different quadrupole fields. Then the emittance was reconstructed with tomography method[3]. Figure 4 shows the result of the reconstruction. This indicates that 80 % normalized emittance is 35 pi mm mrad and that 100 % emittance is about 5.6 times larger than 80 %. This was achieved before the succession of the FEL oscillation and under adjustment of the accelerator parameters.

5 REFERENCES

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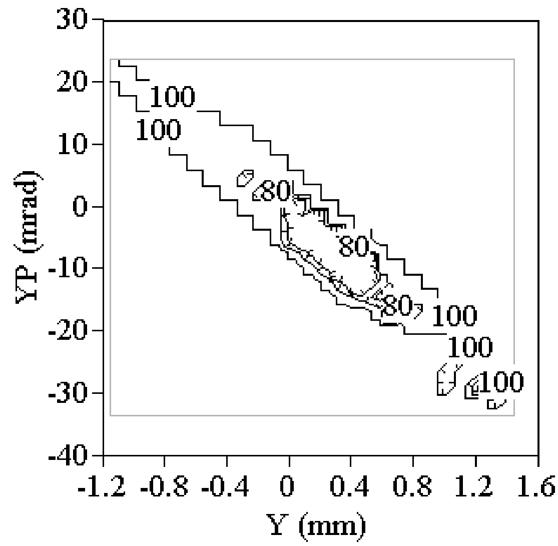

Figure 4: Reconstructed phase space contour of 100 % and 80 % emittance.