Acceleration of a Single-Bunch Electron Beam at Charges Exceeding 70 nC with the ISIR Linear Accelerator

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Abstract

The characteristics and the behaviors of the single-bunch electron beams generated with the L-band linac at The Institute of Scientific and Industrial Research in Osaka University have been investigated. The maximum charge of electrons in a bunch is 73 nC, which has been achieved by the development of the high-current electron gun. The length of the bunch at the maximum charge, which has been measured with a streak camera is 26 ps in FWHM. In the transportation of the single-bunch beam through a chicane-type bunch compressor the peak shift of the energy spectrum of the beam has been observed, which has been attributed to the energy loss due to the coherent synchrotron radiation. The possible application researches using the beams are discussed.

1. Introduction

In advanced researches using electron beams high intensity and high quality beams are required. One of such researches is pulse radiolysis in which a matter is excited with high intensity electrons in a short period. Such electron beams are also used for generating high intensity radiation such as self-amprified spontaneous emission (SASE) in a wiggler, the coherent radiation in various processes and the wakefields for particle acceleration.

At Argonne Wakefield Accelerator [1] an electron charge of 100 nC has been achieved by using a photochathode RF gun. The normalized emittance has been estimated to be about 500 πmm mrad at a charge of 20 nC, which has increased with the charge. The quality of the beams are being improved.

At The Institute of Scientific and Industrial Research (ISIR) in Osaka University single-bunch electron beams are generated with the 38 MeV L-band (1300 MHz) electron linear accelerator (linac) [2]. In 1994 the charge of electrons in the single-bunch beam was increased to be 67 nC/bunch [3]. Recently, a newly developed electron gun [4] has been installed in the linac and the charge of electrons has become 73 nC/bunch in maximum. In the present work the characteristics of the single-bunch beam have been measured. The charges above 100 nC is expected to be acheived in the near future. The beams are being applied to pulse radiolysis experiments and to generating the SASE and the coherent radiation.

2. Accelerator System

The accelerator system of the ISIR linac is schematically shown in Fig. 1. A high-current triode electron gun has been recently developed for the ISIR linac by using the YU-156 cathode-grid assembly (EIMAC) [4]. The area of the cathode is 1.5 times that of the Y-796 assembly (EIMAC) which is commonly used for electron linacs. The structures of these assemblies are nearly the same. In the case of generating a single-bunch beam the maximum pulse width of the beam injected from the gun is 5 ns. The maximum peak current is 30.1 A at an anode voltage of 100 kV. This is the highest current for electron guns of linacs with cathode-grid assemblies. The rise-time of the beam pulse will be made less than 1 ns by using a new grid pulser being under development.

The subharmonic prebuncher (SHPB) has a coaxial single-gap cavity at one end of the inner conductor. Pulsed rf of 20 μs duration is supplied to the SHPB by three 20 kW rf amplifiers independently. An electron beam injected from the gun to the first SHPB at a pulse length shorter than 5 ns forms a single-bunch beam.

Two fundamental bunchers are driven by a 5 MW L-band klystron (E3775A, Toshiba). The accelerating waveguide is driven by a 20 MW L-band klystron (TV-2022B, Thomson-CSF). The ripple on the flattop of the

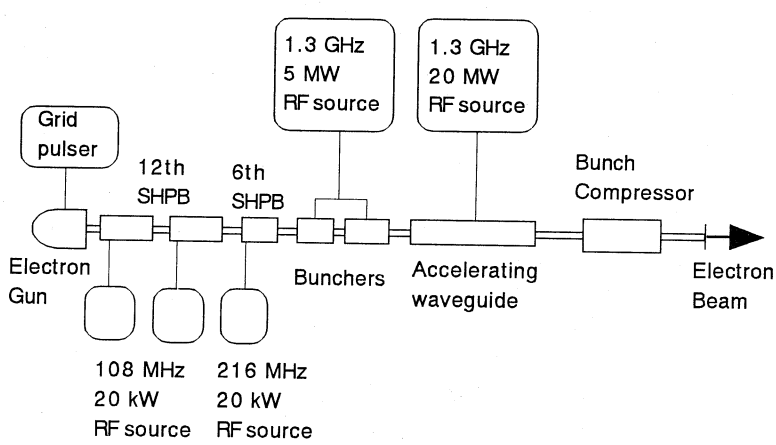

Fig. 1 Schematic diagram of the ISIR linac.

klystron-current pulse is below 0.3%. The lengths of the rf pulse on the flattop for the 5 and the 20 MW klystrons are 3.2 and 3.9 μs, respectively. The maximum beam energy is 38 MeV for no beam-loading.

A chicane-type bunch compressor is located on the axis of the linac after the accelerating waveguide, as shown in Fig. 1. The bunch compressor has four bending magnets. For the energy of electrons of 27 MeV the orbit radius and the bending angle in each magnet are 731 mm and 0.27 rad, respectively. The magnetic field strength is 0.105 T. The vacuum chamber is made of stainless steal and has an inner width of 31 mm. When the compressor is not operated, the beam is transported on a straight path through the compressor.

3. Characteristics of the Single-Bunch Beam of the ISIR Linac

The characteristics of the single-bunch beam generated with the linac were investigated. The maximum charge of the single-bunch beam is 73 nC/bunch. In this case for the maximum charge the operational conditions of the components of the ISIR linac and the characteristics of the single-bunch beam are listed in Table 1. The time profile of the bunch has been measured by observing Cherenkov radiation from the beam using a streak camera, which is shown in Fig. 2. The bunch length is 26 ps in FWHM. From these results the peak current of the beam corresponds to 2.8 kA, which is comparable to one obtained by induction linacs. The results for the measurements also show that the ratio of the number of electrons in the satellite bunches, which appear at an interval of 770 ps around the main bunch, to the total number of electrons is below 2%. The value of the energy spread can probably made smaller because 1.9% has been observed in the case for the charge at 71 nC.

Table 1 Operational conditions of the linac and the parameters of the single-bunch beam.

Injection from the Electron gun
Anode voltage: 106 kV
Pulse width: 5 ns
Peak current: 23 A
SHPB
RF power: 4 kW (at 1st)
14 kW (at 2nd)
14 kW (at 3rd)
Beam conditions
Mode: Single-bunch beam
Energy: 27 MeV
Energy spread (FWHM): 3.7%
Carge/electron bunch: 73 nC
Bunch width (FWHM): 26 ps

The previous work shows that the energy spread of the single-bunch beam has a minimum value of 0.7% at a charge of electrons in a bunch of 33 nC. Below the value of charge the energy spread is about 1%. At the higher charges the spread increases with the charge.

The normalized emittance of the electron beam measured at a charge of 20 nC is about 200 πmm mrad. The value is about 40% of that for Argonne accelerator. The measurement of emittance for the higher charges will be performed.

By the improvement of the grid pulser of the electron gun and by the optimization of the configuration of the magnetic lenses located between the gun and the first SHPB the charge of the single-bunch beam is expected to exceed 100 nC/bunch.

In order to investigate the energy loss of intense electron beams under transportation the energy spectrum of the single-bunch electron beam after passing through the bunch compressor has been measured. The charge and the energy of electron beam are 22 nC and 27 MeV,

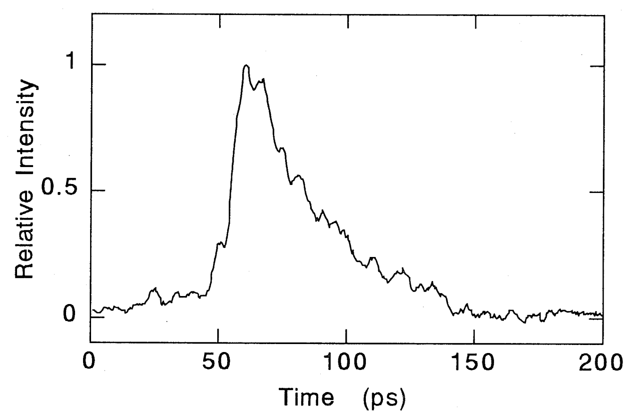

Fig. 2 Shape of the single-bunch beam measured with a streak camera at a time resolution of 5 ps.

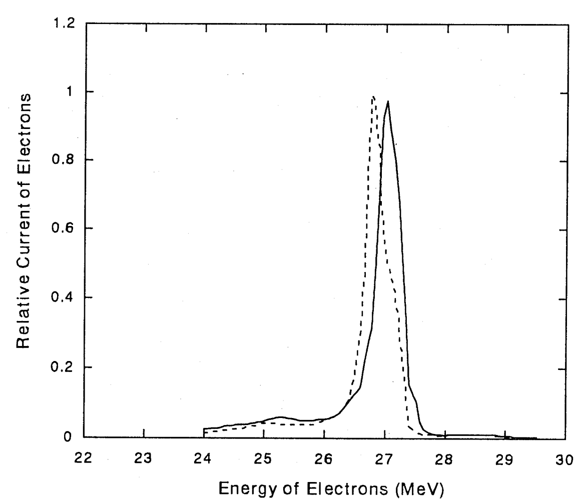

Fig. 3 Energy spectra of the single-bunch beams under operating (dashed line) and not operating (solid line) the bunch compressor.

respectively. The results for the measurement of the energy spectra of the single-bunch beam are shown in Fig. 3. The energy resolution of the analyzer is about 0.1%. The spectrum measured under not operating the bunch compressor shows a typical profile for the single-bunch beam and has an energy spread of 1.6% in FWHM. One can observe 1% peak shift to the lower energy after operating the compressor. The decrease of the averaged energy of electrons in an energy range of 26-28 MeV is 0.5%, which corresponds to a total energy of 3 mJ in the bunch. Modification of the shape of the spectrum is also observable in this figure, which suggests that the intensity of radiation from an electron is different at the different position on the electron bunch. From the evaluation of the energy of radiation in the bunch compressor, the cause of the energy shift observed is attributed to the emission of the coherent synchrotron radiation.

The ISIR linac is being operated also in multibunch beam modes. When the SHPBs are not operated the bunch train has an interval of 770 ps between the bunches. In the more complicated operational conditions using SHPBs, two-bunch or multibunch beams are generated at considerably high beam intensity.

4. Application Researches of the Single-Bunch Beam

The high intensity single-bunch beams generated with the ISIR linac are being applied to establishing high-brightness coherent pulsed light sources in far-infrared regions. A new light source having a continuous spectrum in a submillimeter to millimeter range has been established by using the coherent synchrotron radiation. The coherent radiation is also used for evaluating the shape of the electron bunch. In the experiments for free-electron lasers SASE has been observed at wavelengths of 20-150 μm [5, 6]. The single-bunch beam from the ISIR linac has good characteristics for performing wakefiled acceleration experiments. These are under preperation.

Generation of the single-bunch beams at a bunch length shorter than 1 ps is important for analyzing ultrafast phenomena in pulse radiolysis experiments. Such a short bunch is also useful for generating relatively intense coherent radiation at the shorter wavelengths. The injection from the gun at a pulse width below 1 ns will be carried out in the near future.

5. Conclusion

The maximum charge of electrons in a bunch of 73 nC has been achieved at the ISIR linac. The characteristics of the beam have been measured and it has been found that the beam can be applied to advanced experiments requring high intensity and high quality. By using the single-bunch beam the energy loss of the beam passing through a chicane-type bunch compressor due to the coherent synchrotron radiation has been observed.

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