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SINGLE BUNCH COMPRESSOR AND SIGLE BUNCH SHAPE MONITOR

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Abstract

A single bunch with the charges up to 67 nC is accelerated by the ISIR-Osaka single bunch electron linear accelerator. The bunch length is estimated to be 40 ps in full width and 16 ps in fwhm. In order to compress the bunch length, a bunch compressor with four dipole magnets has been installed in a transport line. The single bunch is compressed into 12 ps in full length, and 9.5 ps in fwhm. The bunch length can be controlled by adjusting the rf phase and the magnetic field of the compressor. The maximum compression rate is estimated to be 30 % for the single bunch with the charge between 10 - 40 nC.

Introduction

The transverse and longitudinal wake fields generated by the high-current bunches limit the number of particles accelerated in the linear accelerators.[1-3] The longitudinal wake fields affect the energy spread and the transverse wake fields increase the beam emittance. These two wake fields depend both on the accelerating structure and the charge distribution in the bunch. The amplitude of the wake fields increases with the bunch intensity. In order to obtain the high luminosity at the interaction point of the linear collider, high-current bunches both with lower energy spread and with lower beam emittance are required. The longer bunch length results in less energy spread than the shorter bunch length, since the longitudinal wake potential decreases with the increase of bunch lengths. On the other hand, shorter bunch length is preferable to reduce emittance growth due to the transverse wake fields, since a large transverse emittance leads directly to large beam diameter at the interaction point and gives rise to reduction of the luminosity.

The energy spread is determined by the net accelerating potential, which depends both on the external accelerating potential and on the longitudinal wake potential.[3-4] The lower energy spread is obtained, when a single bunch is accelerated ahead of the accelerating crest, since the rising slope of the accelerating field can be made to cancel, at least near the bunch center, the negative-going slope of the logitudinal wake potential. The minimum energy spread can be obtained at the optimum rf accelerating phase. With increasing bunch charge, the optimum rf phase increases and the particle energy decreases with the increase of rf phase.

The higher accelerating gradient makes it possible to obtain the lower energy spread at the rf phase near the crest. If the charge distribution of the bunch can be controlled at the fixed accelerating gradient, the optimum charge distribution of the bunch both with the lower energy spread and with the lower emittance can be obtained.

Bunch Compressor

The bunch copmressor with four dipole magnets is designed to produce an achromatic bump in the beam trajectory.[5] Figure 1 shows a schematic diagram of the bunch compressor and a bunch shape monitor. The low energy electrons take a longer path through the bunch compressor than the high energy electrons. When the bunch is accelerated ahead of the crest, the energy of the head of the bunch is lower than the the energy of the electrons in the bunch center, while the tail of the bunch is accelerated at higher energy. After passing through the bunch compressor, the tail of the bunch will catch up the bunch center, and the head of the bunch will fall behind the bunch center. As the result, the bunch length will be shortened with increasing magnetic field strength of the bunch compressor magnet. The shortest bunch length can be obtained at the optimum magnetic field strength. The bunch length will be increased at the field strength higher than the optimum strength, since the bunch tail passes the bunch head and the bunch head falls behind the bunch tail.

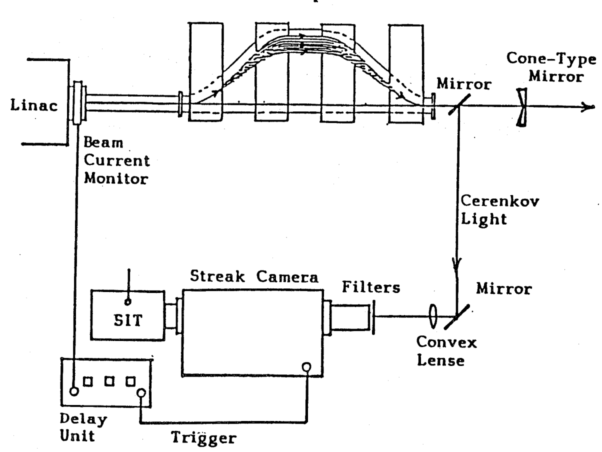

Figure 1. A single bunch commpressor and a bunch shape monitor.

The effect of the bunch compressor is calculated for the single bunch with the bunch length of 16 ps in fwhm and with the full length of 40 ps. The longitudinal wake potentials are calculated for the single bunch passing through a 3 m long L-band linear accelerator with the time domain analysis. In order to minimize the energy spectrum, the single bunch should be accelerated at the positive phase-angle where the negative-going slope of the accelerating voltage waveform is made to cancel with the positive slope of the longitudinal wake potential. Figure 2 shows single bunch with the minimum energy spread expressed in the energy- phase space. The optimum phase angle ahead of the crest which minimizes the energy spectrum increases with the single bunch charge from 5 nC to 20 nC. With increasing the single bunch charge, the average energy decreases and the energy difference between the bunch head and the bunch tail increases. Figure 2 also shows the result of the calculation with the bunch compressor. The shortest bunch length can be obtained at the optimum field strength of the compressor magnet.

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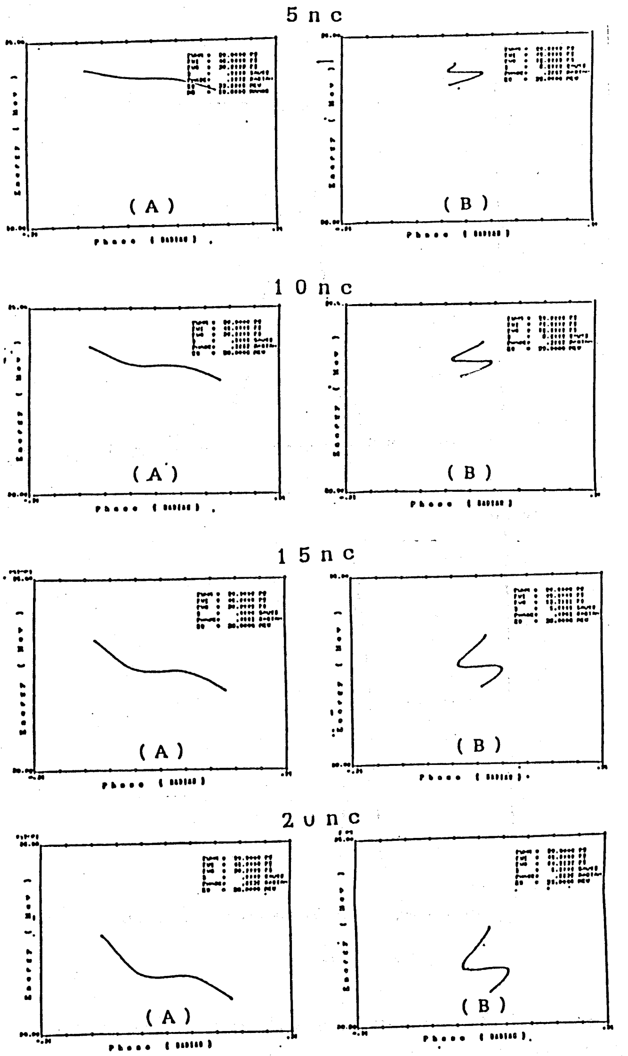

(without bunch compressor) (with bunch compressor)

Figure 2. Single bunch with the minimum energy spread expressed in the energy-phase space.(left) Compressed bunch after passing through the bunch compressor.(right)

Bunch Shape Monitor

In order to investigate the compression effects, the bunch shape should be measured with the time resolution of the order of ps in real time. On such a short-time scale, the optical detection system is more effective than the electric detection system. By using streak cameras, the fine structure pulses of the mode- locked lasers can be measured with the time resolution of picosecond or sub-picosecond.

The Cerenkov light generated by a relativistic electrons passing through a medium can be applied to the observation of the bunch shape. In order to observe the bunch shape with the time resolution of ps, the following subjects should be taken into consideration:

1) The Cerenkov light consists not of the monochromatic wavelength but of the continuous wavelength. Figure 3 shows the typical spectrum of the Cerenkov light generated in the air by 30 MeV electron beam. The spectrum is observed by a multichannel optical analyser with the sensitivity in wavelengths between 300 nm and 1000 nm. The shorter cutoff wavelength is determined by the absorbers, such as air, VUV lenses and an optical guide of the multi-channel optical analyser. The narrow

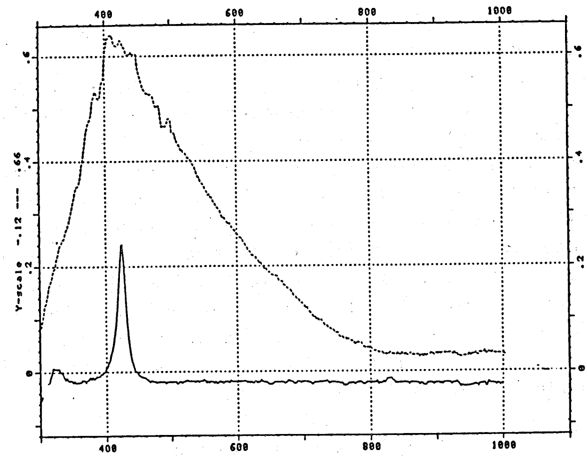

Figure 3. The spectrum of the total photons in the Cerenkov light generated in the air. An monochromatic light is selected by an interference filter of 430 nm in wavelength.

band in wavelength enebles to measure the bunch shape with the picosecond time resolution, since the time delay is generated by the difference of the transit time in the dispersive medium such as radiators, air and lenses. The time delay between 200 nm and 850 nm is estimated to be 1.8 ps/cm in VUV lenses.

2) The Cerenkov light generated at the point on the beam axis and transmits at the Cerenkov angle θc. The optical guide system should be designed both to guide the light effectively and to reduce the transit time spread due to the difference of the light path in the system.

3) Gases are useful to generate the Cerenkov light. As the refractive index of air is 1.00027311 at 1 atm and 20 C, the electrons with the energy higher than 21.4 MeV radiate the Cerenkov light at the beam window. The Cerenkov angle slightly depends on the energy (0.93 at 30 MeV and 1.05 at 35 MeV).

The diameter of the Cerenkov light generated in air is estimated to be 3.2 cm at the distance of 1 m. If a plane mirror is used to reflect the Cerenkov light, the optical hollow beam with the 3.2 cm of thickness and increasing diameter with the rate of 32 cm/10 m. If the convex lenses are utilized to focus the Cerenkov light, the light spot of ring shape will be obtained at the slit of the streak camera. A small part of the photons in the Cerenkov light are guided into a slit. If the Cerenkov light is converted to the parallel light, the total photons can be focused into the point spot at the slit and the number of photons into the slit will be increased. A cone-type mirror is designed to convert the Cerenkov light to the parallel light beam (see Fig. 1). The mirror is made of Aluminum with the surface angle of 0.47, which is the half of the Cerenkov angle at 30 MeV. The surface roughness on the Aluminum mirror is estimated to be about 50 nm, which is about ten times shorter than the interest wavelength of the Cerenkov light.

Optical Guide System

The converted parallel light is guided by the plane mirrors to the streak camera in the control room. The total light path is estimated to be about 20 m. The light is focused at the slit of the streak camera. In order to avoid the transit time spread, an interference filter is installed in front of the slit. The interference filter transfers 38 % of photons in the wavelength between 425 - 435 nm. The higher cutoff filter is also installed to cutthe higher mode of the interference filter. The slit width of the streak camera is adjusted to be 4 μ m so as to obtain the time resolution of 2 ps. The spot size of 1 - 2 mm can be obtained at the slit.

Streak Camera System

The streak camera system consists of a streak camera (Hamamatsu Photonix, C-1098), a data processing system and an SIT camera. The streak camera is triggered by a beam waveform voltage from the beam current monitor at the exit of the linear accelerator in order to avoid the trigger jitter. The time jitter between a trigger signal and a sweep voltage in the streak camera is estimated to be about 10 ps. As the decay time of image on the SIT is about 0.6 s, the superimposed streak image increase the time resolution at the higher repetition rates than 1.5 pps. In order to obtain the time resolution less than 2 ps, the linear accelerator is operated at the repetion rate of 1 pps. The beam is injected at 1 pps, while the the rf power is supplied to the linear accelerator at the higher repetion rate of 10 pps in order to maintain the thermally stable condition.

Results of Compression

Figure 4 shows the typical bunch waveforms with and without the bunch compressor. The single bunch of 20 nC is accelerated at the phase-angle of 0.242 rad ahead from the rf crest. The full length of the bunch is compressed from 40 ps to 12 ps, while the bunch length in fwhm is compressed from 16 ps to 9.5 ps. The maximum compression rate is estimated to be 30 % for single bunch with the charge between 10 nC and 40 nC. Figure 5 shows the compression rate and the accelerating rf-phase of the single bunch for the single bunch with 20 nC at the fixed magnetic field of 0.96 kGauss. The energy distribution in the single bunch directly affects the compressed bunch shape. As the energy distribution in a single bunch depends on the accelerating rf-phase, the compressed full length is also depend on the rf- phase.

References

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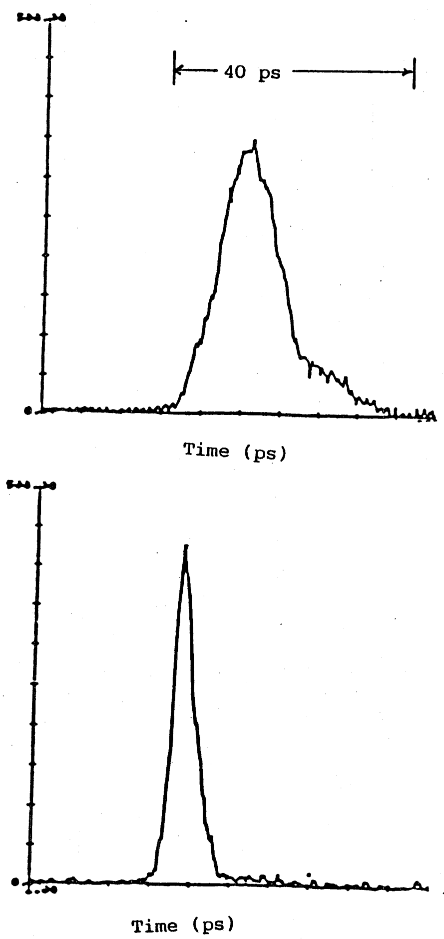

Figure 4. Bunch waveform without bunch compressor and with bunch compressor.

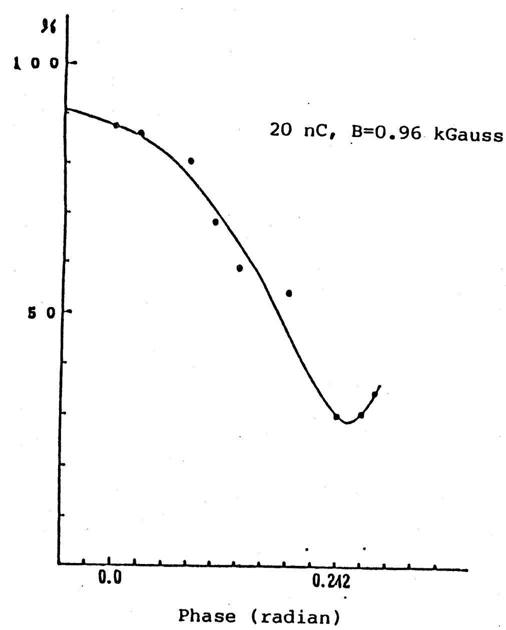

Figure 5. Compression rate of the 20 nC single bunch.