BUNCH COMPRESSION USING THE TRANSPORT LINE AND SHORT BUNCH REVOLVING IN NEWSUBARU

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Abstract

The electron bunches was compressed to a few pico-seconds rms by the transport line from SPring-8 linac to NewSUBARU storage ring (NewSUBARU). And the compressed bunch was circurated for some tens of turns after injection while maintaining the short bunch length in the NewSUBARU. The NewSUBARU was set to a quasi-isochronous condition. Bunch length in the NewSUBARU was measured the streak camera and maicrowave detector. There data was not accord by the deformation of the bunch structure.

INTRODUCTION

The production of short bunches is an important technique, since bunches on a millimeter scale are necessary for time-resolved experiments and for stable production of coherent synchrotron radiation (CSR). Some methods have been proposed for producing a short electron bunch in a storage ring, like the laser-slicing method [1] and the quasi-isochronous (QI) operation of a storage ring [2]. The ring stores electron bunches as short as a few pico-seconds in a stationary state. These two methods produce more stable radiation than that produced by a linac. However, the beam charge in a short bunch is much smaller than in a bunch produced by a linac.

This paper reports a demonstration of another method, which is based on a combination of a linac and a storage ring. A short, high-current bunch is produced with a linac and a bunch compression system. The short bunch is injected into an isochronous ring, and circulates for many turns. The bunch length becomes longer even in an ideal isochronous ring because of the longitudinal radiation excitation, but this takes many turns [3]. This method has several merits: (1) a bunch with higher charge is possible in a storage ring than with the existing two methods; (2) one short bunch produced by the linac is reused at every turn of the ring that it makes; (3) the repetition rate of the radiation pulse can be very stable in an isochronous ring; (4) pulsed light is obtained in every beam line of the storage ring; (5) a few pico-seconds long pulse is possible with no special expense; and (6) future improvements of the linac beam quality would give better performance of this method.

The aims of this report are (a) to demonstrate the method, (b) to investigate the problems associated with it, and (c) to clarify the limitations of the present hardware, the SPring-8 linac, and the NewSUBARU. The results of our experiment provide suggestions for future light source projects with an energy recovery linac and a more sophisticated short-bunch circulator [4].

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EXPERIMENTS AND MEASUREMENTS

Bunch Compression of Linac Beam

Figure 1 shows the layout of the SPring-8 linac [5], the energy compression system (ECS) [6], the booster synchrotron, and the NewSUBARU [7]. Tables 1 and 2 show the main parameters of the linac and the NewSUBARU. In normal operation, the typical bunch length of the linac bunch was about 20 ps (full width), and the energy spread was 0.7% (full width) at 1 GeV. However, in this experiment, the chicane of the ECS was bypassed and the acceleration cavities of the ECS were used to compress the bunch as it passed through the transport line to the NewSUBARU. Figure 2 shows the simulation of the bunch length from the ECS to the injection point of the time profile and η-function.

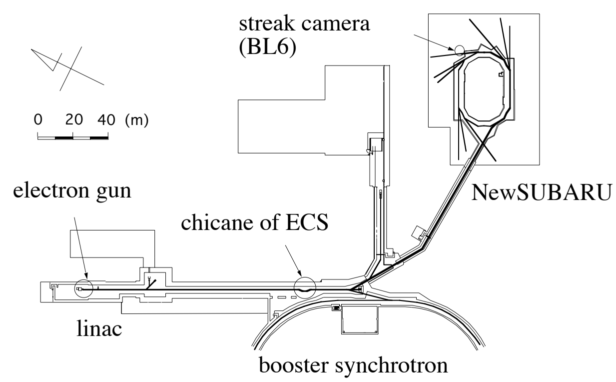

Figure 1: Layout of the SPring-8 linear accelerator, the energy compression system (ECS), the booster synchrotron, and the NewSUBARU. The streak camera is placed in beamline 6 (BL6) of NewSUBARU.

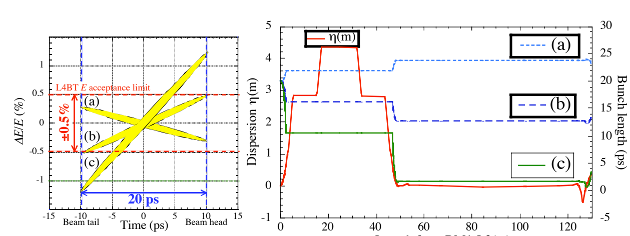

Figure 2: Simulation of the bunch length from the ECS to the injection point. Each line corresponds a difference of phase space of a left-hand figure.

Figure 3 shows the bunch length measured by a streak camera in beamline 6 (BL6) [8]. Stronger compression was in principle possible but the transport line would not accept the larger energy spread of such a compressed bunch. The energy acceptance of the transport line is 1 % full width. The time profile was fitted to a Gaussian distribution for the subsequent analysis, although the fitting was not good.

Table 1: Main Parameters of the Linac with the ECS

RF frequency	2856 MHz
Transverse emittance at 1GeV	71π□nm
Micro bunch length (FWHM)	20 ps
Energy spread (full width)	0.6 %
Micro bunch charge	0.03-0.3 nC

Table 2: Main Parameters of NewSUBARU at 1 GeV

RF frequency	500 MHz
Harmonic number	198
Linear momentum compaction factor	0.0013
Natural energy spread (σ)	0.047 %

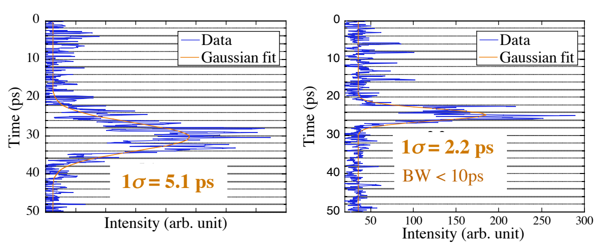

Figure 3: Time profile of the normal injection bunch (a) and the compressed bunch (b). Bunch length was measured at BL6.

Bunch Length Measurement

The NewSUBARU has six modified double bend achromat (DBA) cells with an 8° inverted bending magnet between two 34° normal bending magnets. These special cells facilitate control of the linear momentum compaction factor α_1 while maintaining the achromatic condition. The nth momentum compaction factor, α_n, is defined by

$$\Delta L / L_0 = \alpha_1 \delta + \alpha_2 \delta^2 + \alpha_3 \delta^3 + \dots . \quad (1)$$

Here L_0 is the circumference, ΔL is the change of the path length for one revolution, respectively, and δ is the relative energy displacement. At the NewSUBARU, α_1 and α_2 are adjustable but α_3 is not ($\alpha_3 \approx 0.5$).

Figure 4 shows the bunch length in the ring after injection for different values of α_1. A small negative value of α_1 is better for maintaining a short bunch because it reduces the spread caused by α_3. Figure 5 shows the evolution of the time profile in a quasi-isochronous ring for the best condition ($\alpha_1 = -6 \times 10^{-5}$). The injected beam charge was 24 pC/bunch in this case. The bunch length (σ of the fitted Gaussian) was still less than 3 ps after 50 turns (20 ps).

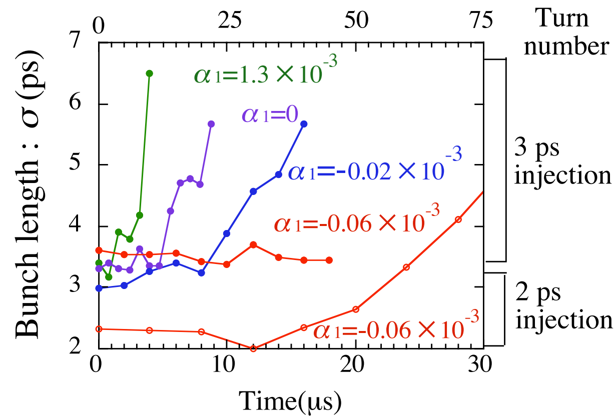

Figure 4: The elongation of the bunch length after injection for different values of α_1. The initial length was not the shortest, because the buncher phase of the linac was not optimized at that time.

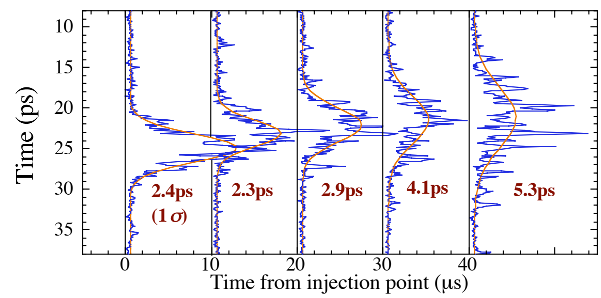

Figure 5: Evolution of the time profile of the bunch after injection, for $\alpha_1 = -6\times10^{-5}$.

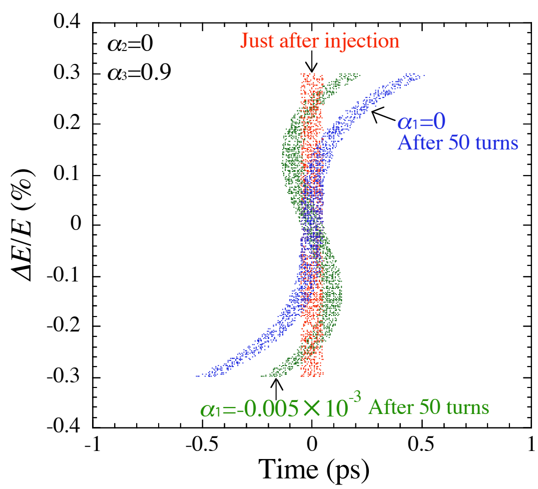

Figure 6: Tracking simulation of phase spece distribution for this experiments case.

In Figure 6, the tracking simulation results of phase spece distribution for this experiments case is shown. For higher order momentum compaction factor, the bunch length is grown up by $\alpha_1 = 0$ lattice than $\alpha_1 = -6 \times 10^{-5}$ lattice.

CSR Power Measurement

The relative CSR power was measured by a Schottky diode detector, which was sensitive to radiation in the frequency range 90–140 GHz. The turn-by-turn change of the CSR power is shown in Fig. 7. The reduction of the CSR power was due to a reduction of $f(\omega)$. In the frequency range of the detector, f is sensitive to small changes in the length and shape of the bunch; the shape may be angular or a smooth Gaussian shape.

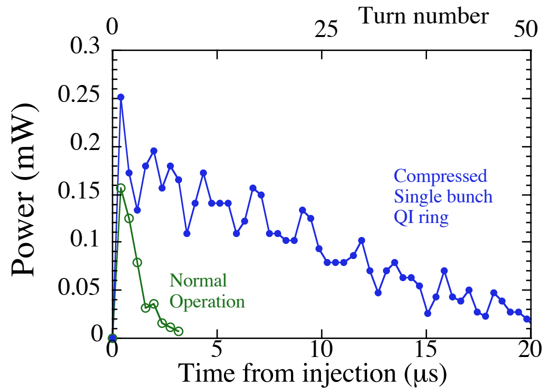

Figure 7: The turn-by-turn CSR power after injection. The bunch charge was about 20 pC/bunch in both cases, where there were three bunches in a pulse.

The radiation power $P_{tot}(\omega)$ from a short bunched beam containing N electrons is given by [9, 10]

$$P_{tot}(\omega) = p(\omega)[N + (N^2 - N)|f(\omega)|^2], \qquad (2)$$

where $p(\omega)$ is the power at a frequency ω radiated from one electron, and $f(\omega)$ is the form factor calculated from the azimuthal charge distribution $\rho(z)$ using

$$f(\omega) = \int \rho(z)\exp(i\omega z/c)dz. \qquad (3)$$

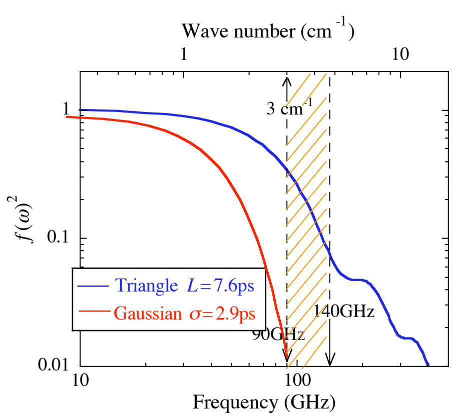

Figure 8: The form factor of the triangle bunch and the guassian bunch. Mesh area is the sensitive region of the Schottky diode detector.

DISCUSSIONS

The bunch was compressed by the transport line. And we have demonstrated that and the NewSUBARU could keep a bunch as short as 3 ps and with a charge of about 20 nC for 50 turns. Here we mention some additional results and problems encountered in the experiments:

(1) Adjustment of the higher-order α's was essential for keeping a short bunch in the storage ring. With a small value of α_2, we observed a considerable increase in the bunch length.

(2) The shot-by-shot fluctuation of the shape and charge of the injected bunch was also considerable.

(3) The CSR power from a short bunch comparable in length to the wavelength depends strongly on the form factor. This means that the bunch should be much shorter than the wavelength to obtain stable CSR.

The beam performance at present does not reach that achieved by the existing methods mentioned earlier. However the improvement of the bunch charge would not be difficult and more careful adjustment of the linear and higher order momentum compaction factor would keep the short bunch longer in the ring. In order to achieve much shorter pulses, we need to upgrade the hardware. In particular, the linac and the transport line were not originally designed for short-pulse injection and leave much room for improvement.

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