STORAGE RING AS A LINAC BEAM MONITOR – ITS OPERATION AND CONTRIBUTION TO THE STABLE TOP-UP INJECTION

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Abstract

We have used the electron storage ring, NewSUBARU, as a beam monitor of the SPring-8 linac. The time and transverse profiles of the injected linac beam in the ring are recorded in a frame of a dual-sweep streak camera. A measurement through synchrotron oscillation or betatron oscillation periods gives multi-dimensional beam structure. We report how we use the system and its contribution to the stable beam injection of the ring.

INTRODUCTION

The SPring-8 linac [1] has been operated as an injector to the electron storage ring, NewSUBARU (NS) [2]. A fine parameter tuning is required for the stable top-up injection, because of a small ring acceptance and a radiation safety regulation. In the tuning process, a single shot linac beam monitor has been a powerful diagnostic to understand what is happening at the injection because the linac beam has shot-by-shot fluctuation.

We used the storage ring as a linac beam monitor. The dual sweep streak camera, set at the beam-line of the storage ring, recorded profiles of the injected linac beam for many revolutions in one camera frame. These images enabled reconstruction of multi-dimensional linac beam parameters. The measurement took place at least once after every long shut down. It functioned as a final check of the linac beam tuning before user operations.

The measurements gave better understanding of the injection process and is also a strong driving force for the improvements of the linac beam quality.

PARAMETERS OF DAILY OPERATION

Fig. 1 shows the layout of the SPring-8 linac, the booster synchrotron, and NS storage ring. Table 1 shows the main parameters for the linac. The pulse width of the linac beam is normally 1 ns, which contains 3 linac bunches. The rf synchronization system between the linac and the ring [3] enables an injection to a single rf bucket of the ring with rf frequency of 500 MHz.

The listed transverse emittance was the average of many shots, measured by Q-scanning at the beam transport line. The longitudinal parameters were obtained from the measurements described in this report [4]. The listed bunch length and the energy spread were the average of 10 shots.

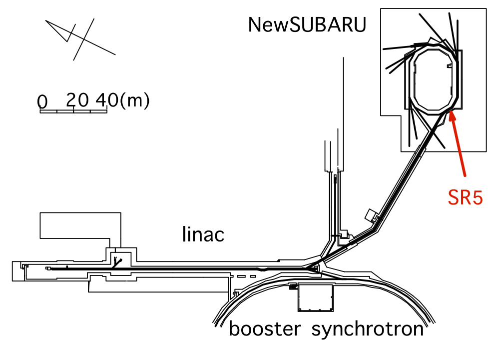

Figure 1: Layout of the 1 GeV SPring-8 linac, the booster synchrotron, and the NewSUBARU storage ring.

Table 1: Main Parameters of the Linac

Electron energy	1 GeV
Rf frequency	2856 MHz
Common pulse rate	1 Hz
Common pulse width	1 ns
FWHM Bunch length; front/middle	10 ps / 14ps
Full energy spread; front / middle	0.4% / 0.6%
Transverse emittance (HWHM^2)	100 π nmrad.

MEASUREMENTS USING STREAK CAMERA

How to Use Dual Sweep Image

Fig. 2 shows dual sweep images of the injected linac beam obtained at different three operation cycles. A time profile at the injection timing gives the bunch structure in a macro pulse, and its evolution with time shows the synchrotron oscillation in the ring. Fig. 3 is the mountain view of the time profile obtained from the middle image of Fig. 2. The time profile at after 1/4 of synchrotron oscillation period gives the energy profile of the injected linac beam.

Fig. 4 shows the results obtained in these 7 years. It shows the improvement of the energy spread of the linac beam, which is now small enough for the injection. The number of bunches (gate pulse width) was not fixed because it was optimized for the pulse charge to the booster synchrotron.

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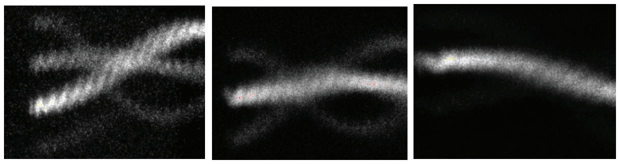

Figure 2: Typical dual-sweep streark camera images after the injection. The vertical axis is the ring rf phase with full scale of 1.27 ns. The horizontal axis is the revolutions in the ring with full scale of 0.123 ms.

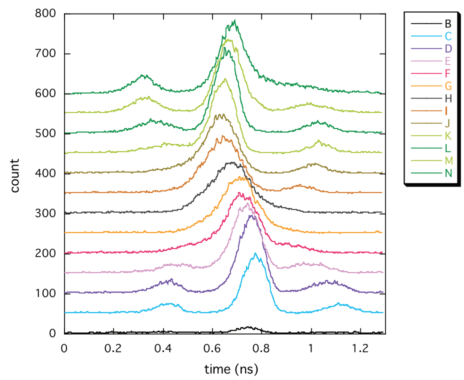

Figure 3: Evolution of the time profile.

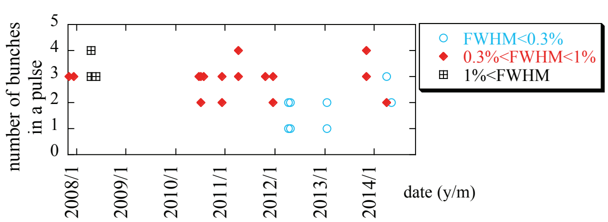

Figure 4: Longitudinal linac beam parameters in 7 years.

Fig. 5 shows an image with faster revolutional (horizontal) sweep, which gives turn-by-turn transverse beam profile. We set dove prism on the line, so that the horizontal spot shape gave the vertical beam shape. Fig. 6 shows the evolution of the transverse profile for 6 turns, from which we calculate the dipole mismatch, transverse emittance, and Twiss parameters [5, 6].

Shot-by-Shot Fluctuation and Injection Efficiency

Fig. 7 (a) shows the shot-by-shot fluctuation of the bunch structure in a macro pulse. The linac bunch appears at the fixed ring rf phase because of the perfect rf synchronization. The fluctuation of the bunch structure was produced by time jittering of the gate pulse for the thermionic electron gun.

Assuming the fixed gate pulse shape, although it also fluctuated, we re-constructed the pulse shape. Moving the start timing of each shot so that their peaks make one envelope. This envelope was identical to the gate pulse shape. As shown in Fig. 7 (b) the base width of the gate pulse was 1.2 ns, where the r.m.s. of the time jittering was 0.12 ns. Fig. 8 shows the profile of the jittering.

The main source of the jittering is still not identified. We fixed one timing module, which had a jittering of 0.05 ns r.m.s., but we have no meaningful improvement.

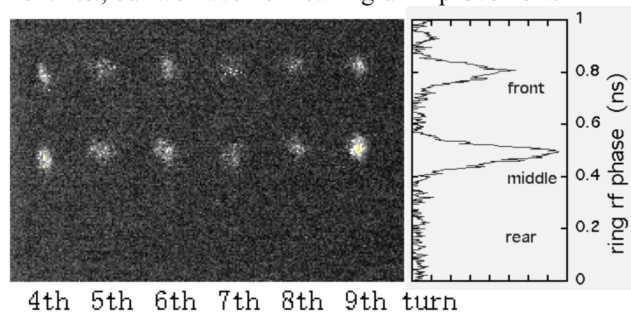

Figure 5: Dual Sweep streak camera image of the injected beam for 6 turns. The revolution period is 0.396 µs.

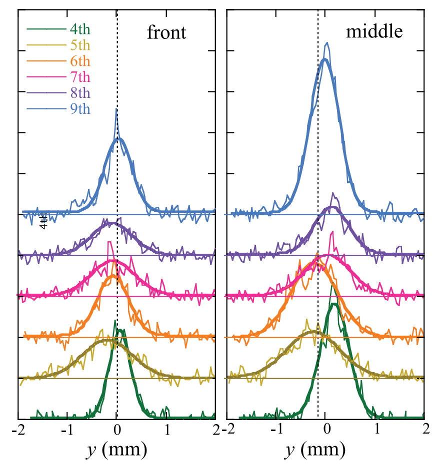

Figure 6: Vertical beam profiles of 6 turns of the front and the middle bunch. The profiles are fitted with Gaussian.

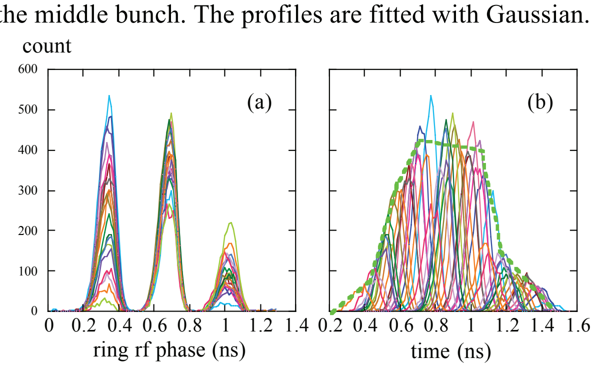

Figure 7: Linac bunch structure (a) and the effective pulse structure reconstructed with the correction of timing jitter.

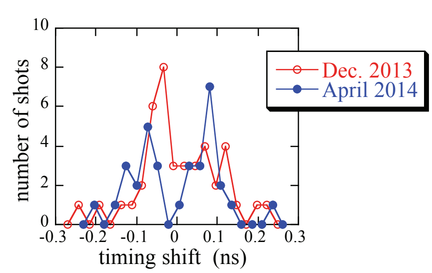

Figure 8; Time jittering (timing distribution) of the gate pulse at before and at after fixing the timing module.

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Fig. 9 shows a correlation of the timing with the injection efficiency. It looked as if the rf phase does not have enough acceptance. However, the parameter survey of the ring energy and phase proved an enough ring rf acceptance. It suggested that the bunch structure had a correlation with transverse beam parameters, which were essential for the injection efficiency.

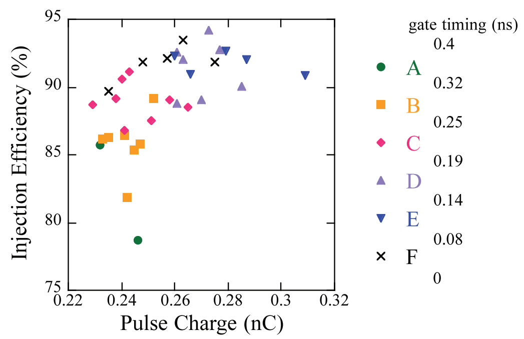

Figure 9: Injection efficiency for different bunch structure. The bunch structure was represented by the timing shift.

Data Analysis of a Typical Shot

The turn-by-turn oscillation of the vertical beam position y and the beam size σ^2 were obtained as Fig.6 and were fitted with the following sinusoidal functions:

$$y = A_0 + A_S \sin(2\pi\nu_y N) + A_C \cos(2\pi\nu_y N) \quad (1)$$

$$\sigma^2 = B_0 + B_S \sin(4\pi\nu_y N) + B_C \cos(4\pi\nu_y N) \quad (2)$$

Here ν_y =2.224 is the vertical betatron tune and A_0, A_S, A_C, B_0, B_S and B_C are fitting parameters. Fig. 10 shows clear difference of dipole oscillation between two bunches and their dependence on the bunch structure. This results proved the correlation of the beam orbit with the bunch structure.

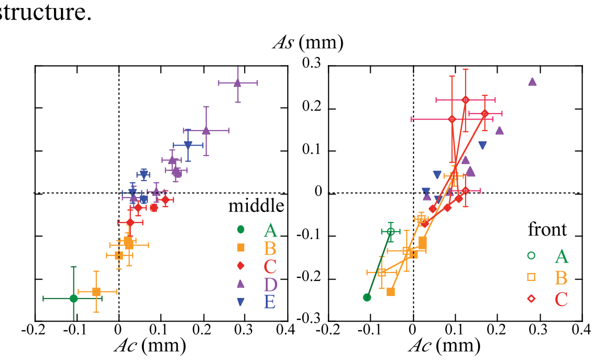

Figure 10: Shot-by-shot fluctuation of the dipole oscillation of the middle bunch (left) and with those of the front bunch (right). The oscillation of the different bunch in the same shot was connected with lines.

Bunch-by-Bunch Energy Profile

Fig. 11 shows the typical streak camera images for the measurement of energy profile. Fig. 12 shows the energy profiles of 4 shots for the front and the middle bunch. The different bunch had a different energy profile, and the each had a bunch charge dependence. The bunch sometimes had two energy components. The energy profile data would be used to understand the delicate bunching process at after the electron gun.

When the beam had a large energy displacement, we adjusted the injection energy of the booster synchrotron with the linac at the beginning of the next cycle.

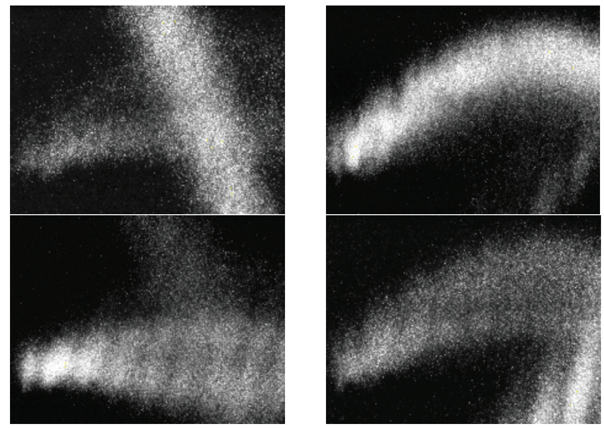

Figure 11: Synchrotron oscillation of a bunch. The vertical and the horizontal full scales are 0.32 ns and 0.6 μs respectively. The front bunch (left two images) or the middle bunch (right two) were injected at the synchronous phase. The steep crossing lines were the light from the other bunch.

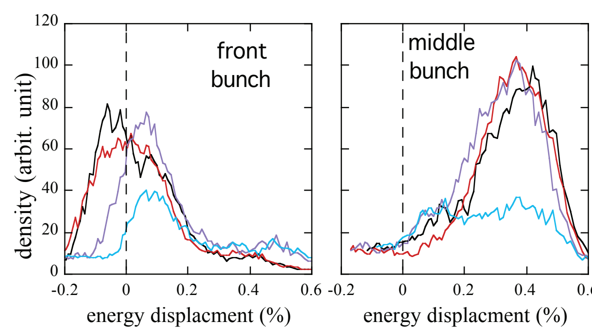

Figure 12: Shot-by-shot fluctuation of the energy profile. The horizontal axis is the displacement from the ring energy. A weak bunch had a larger energy spread.

SUMMARY AND DISCUSSION

We succeeded to measure multi-dimensional beam profile of the linac beam, although it had a shot-by-shot fluctuation. In order to make the injection process clear, we need a measurement of a correlation of the horizontal parameter with the longitudinal bunch structure.

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